Unmanned Aerial Vehicle (UAV) Cargo System

For Integrated Communications Navigation and Surveillance (ICNS) Conference

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Outline

- Background
- Problem & Mission Statement
- System **Requirements** vs. **Technology** Capability
- Describe the **Concept of Operations**
- Describe the **Avionics Architecture**
  - **Components**
  - **Relationship between components**
- Describe the results of **Reliability Analysis**
- Summary of **Business case**

Background

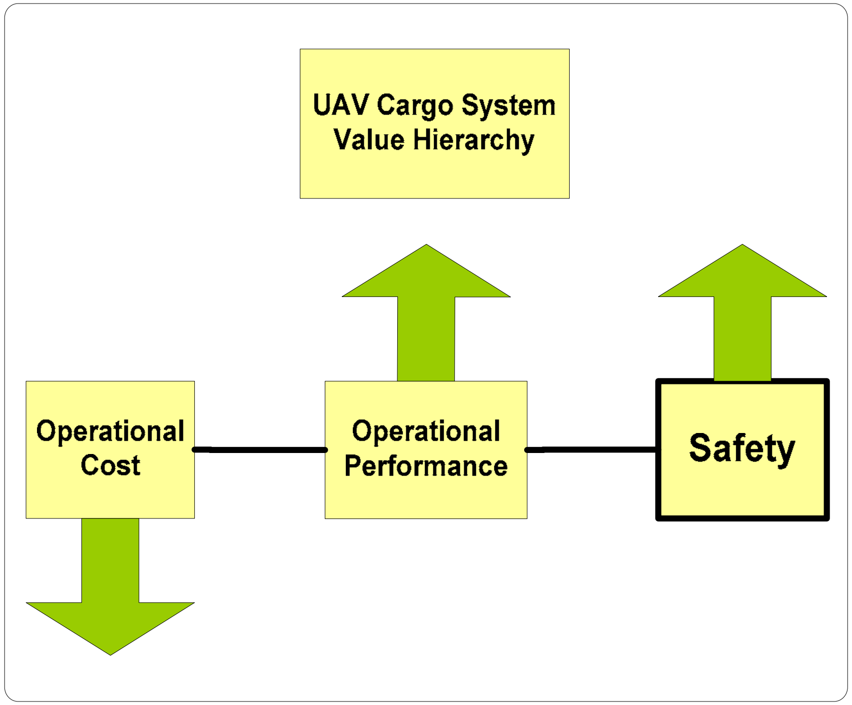
- Driven by economic demand that is not currently being satisfied
  - Cargo demand increasing 15%/year internationally
  - 7%/year domestically

Reference: Rediess, Herman A. "Airport-Independent Uninhabited Air Vehicle Cargo System Concept"

Source: 1995-2002; U.S. Air Carriers, Form 41, U. S. Department of Transportation., www.dot.gov/strategic-plan

Problem Statement

- Develop a preliminary design of a UAV Cargo System
- Simulate and analyze the safety and feasibility of the system performance
- Analyze costs and benefits for investment decision
- Ultimately to be certified by FAA
- Determine the feasibility of the business case



Mission Statement

- Design an Unmanned Aerial Vehicle (UAV) Cargo System
  - **8 hours Just In Time (JIT) delivery for business case**
  - **Provide new level of cargo service 24/7 for light weight/high value cargo**
  - Meet the FAA Safety Standard
  - Automated
  - Efficient
  - Cost effective
- Public Airport-independent
- Provide an all weather autonomous landing capability
  - Achieve fully coupled precision approach meaning it will autonomously land with flight guidance and control system (comparable level of performance like CAT III B)

Reference: Rediess, Herman A. “Airport-Independent Uninhabited Air Vehicle Cargo System Concept”

Value Hierarchy Overview

- 8.0 UAV Cargo System
  - 8.1 Min. Operational Cost Wt=0.1
    - 8.1.1 Design Team Wt=0.1
    - 8.1.2 Insurance * Wt=0.1
    - 8.1.3 Maintenance $ Wt=0.3
    - 8.1.4 Update Wt=0.2
    - 8.1.5 Redundancies Wt=0.3
  - 8.2 Max. Operational Performance Objectives Wt=0.3
    - 8.2.1 Time of Operation (24/7) Wt=0.3
    - 8.2.2 Reliability WT=0.2
    - 8.2.3 Cargo Flight Quality Objectives Wt=0.1
    - 8.2.4 Availability Objectives Wt=0.2
      - 8.2.4.1 Operation MTBF Wt=0.5
      - 8.2.4.2 Operation MTTR Wt=0.5
    - 8.2.5 Flexibility Wt=0.2
      - 8.2.5.1 Compatibility w/ SW&HW Wt=0.7
      - 8.2.5.2 Weather Wt=0.3
  - 8.3 Max. Safety Wt=0.6
    - 8.3.1 Failure Rate Wt=0.5
      - 8.3.1.1 Redundancy Wt=0.5
      - 8.3.1.2 Human Backup Wt=0.1
      - 8.3.1.3 Accuracy Wt=0.2
      - 8.3.1.4 Take-Off / Landing Wt=0.2
    - 8.3.2 Security * Wt=0.5
      - 8.3.2.1 Navigation Tracking Wt=1

* Out of Scope

Requirements vs. Technology Capability

Requirement

“What”

- System shall provide new level of service
  - Just In Time (JIT) delivery within 8 hours

“How”

- Air Transportation
  - Operate directly from and to Industrial Park (IP)
  - Use existing airplane and avionics

View Graph Example

Class A Airspace

> 18,000 Ft.

< 18,000 Ft.

UAV Cargo Planes

Cessna Grand Caravan

Industrial Park 1

Industrial Park 2

References: http://www.maip.com, http://www.aircraft.com, http://www.cinl.com/i-parks.htm

Current Cessna Caravan

- *Cessna Caravan* is already used for cargo delivery service which is certified by FAA

- GPS Navigation
  - TSO- C129 A1
  - Approach Certified
- Multi Function Display
  - Traffic (ADS-B)
  - Terrain
  - Weather (FIS-B)
- Data link Radio
  - UAT

Reference: http://supercargomaster.cessna.com/index.chtml

Requirement

“What”

- Autonomous Takeoff, En-Route, and Landing

“How”

- Avionics (e.g. fully coupled precision approach = CAT III B auto landing)
  - WAAS/GPS
  - Radar Altimeter
  - EGPWS
  - Vision Positioning System

Requirement

"What"

- See (Senses) and Avoid

"How"

- Redundant and Diverse Collision Avoidance & Surveillance Sensors
- Aircraft Collision Avoidance
  - ADS-B
  - TIS-B
  - TCAS II
- Terrain Collision Avoidance
  - EGPWS
  - Radar Altimeter
  - Vision Positioning System

Requirement

"What"

- Avoid Severe Convective Weather Conditions Autonomously

"How"

- Weather Avoidance Avionics
  - FIS-B
    - Icing Altitude (Icing Boots)
    - Convective Weather Cells

Requirement

"What"

- Meet FAA Safety Regulations

"How"

- Class E Airspace
- Fly under IFR
- Monitored by Human Operator in Ground Station
  - Monitor up to 6~7 UAVs and increase as experience gained

Requirement

“What”

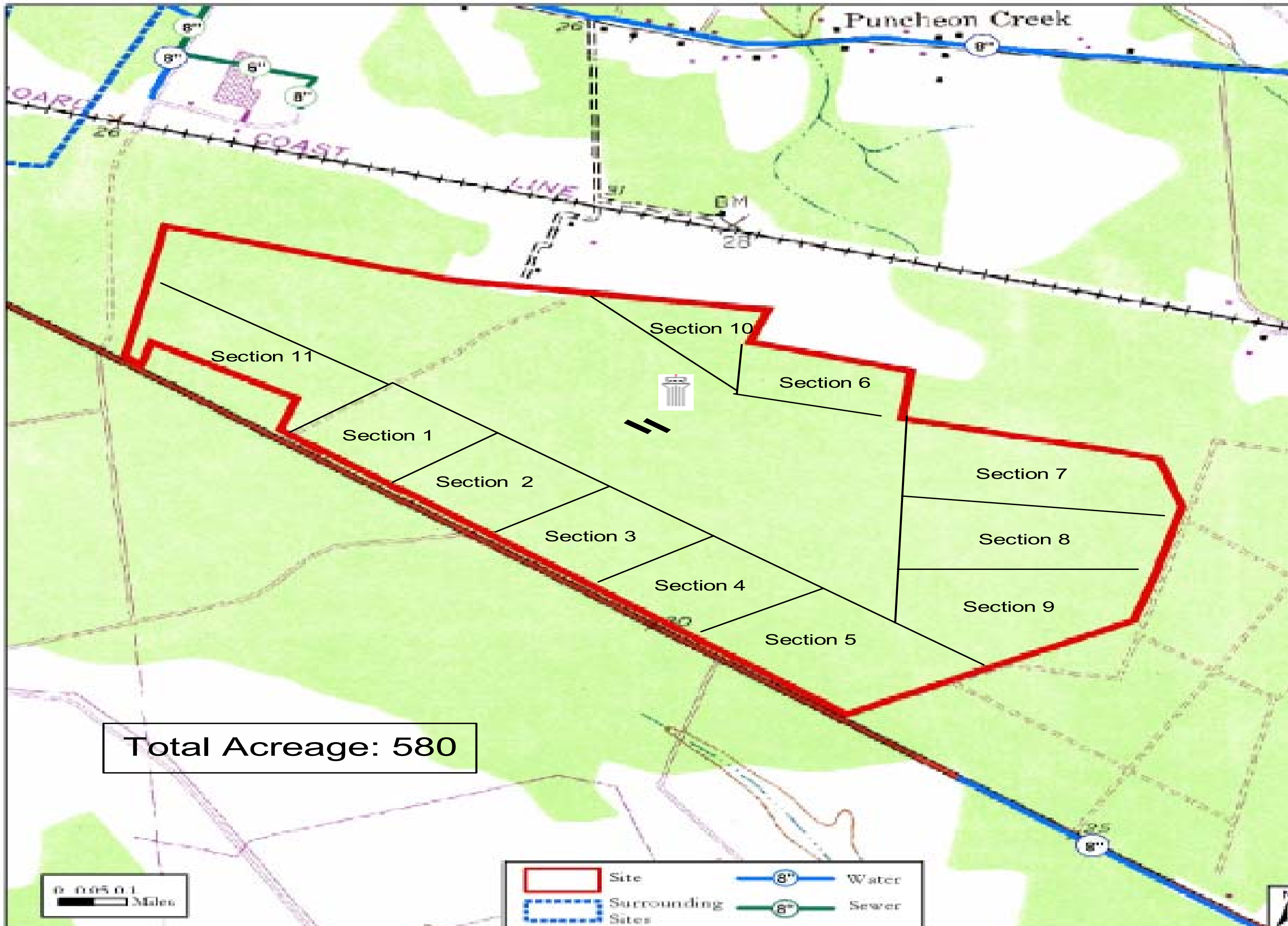
- No Major Ground Infrastructure Changes in IPs

“How”

- Data Links
- ADS-B Ground Station
- TIS-B Ground Station
- FIS-B Ground Station
- IP parking lots for runways

Runway Space for IP

Georgetown County Business Park, SC



Reference:

http://www.teamsc.com/teamscpdfs/siteFliers/844-Topo%20Map.pdf

Overall System Assumptions

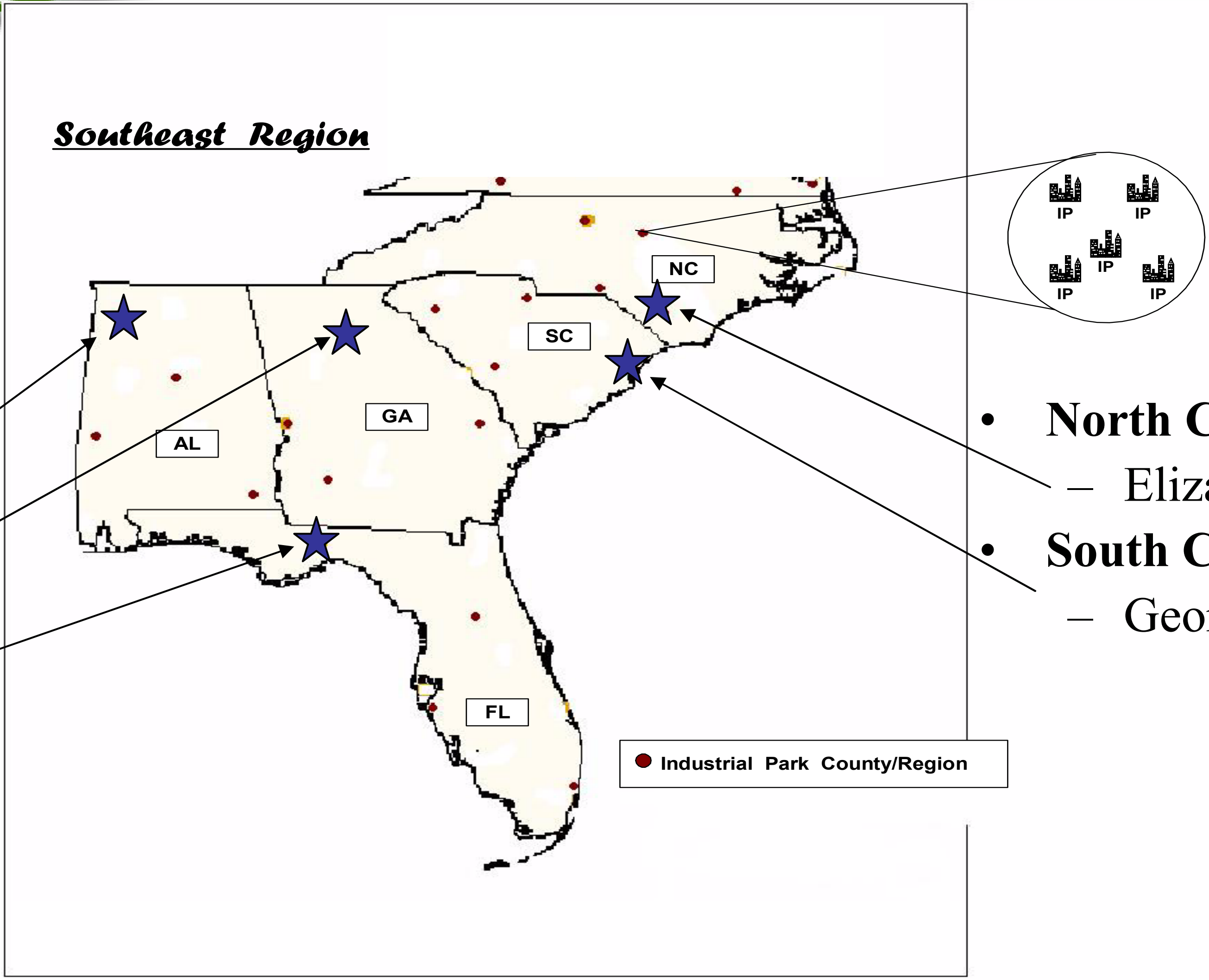
- Public Airport-independent ground infrastructure and Communication Data Link between ATC-UAVs already in place and operate accurately and reliably
- Sufficiently reliable Landing will ensure the Take-Off portion of the flight

CONOP Parameters

- As for transitional period human operator will be used to build confidence from our customer and they will monitor at least 5 UAVs and increase as experience gained
- Human in each IP ground operation center
- Shipping Minimum Distance 300 mi
- Shipping Maximum Distance 900 mi

Selected Industrial Parks Map

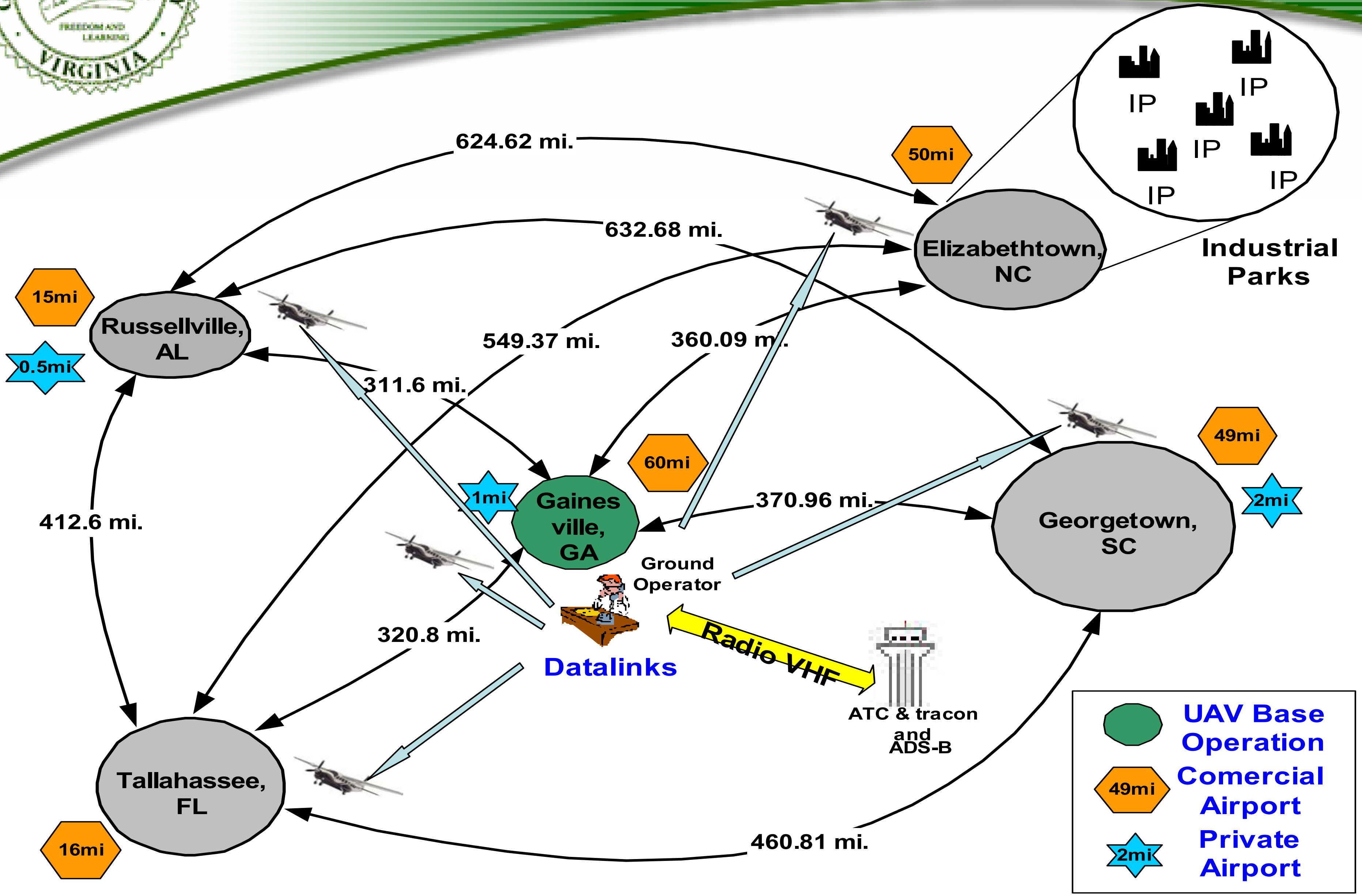
- **Alabama**
  - Russellville
- **Georgia**
  - Gainesville
- **Florida**
  - Tallahassee



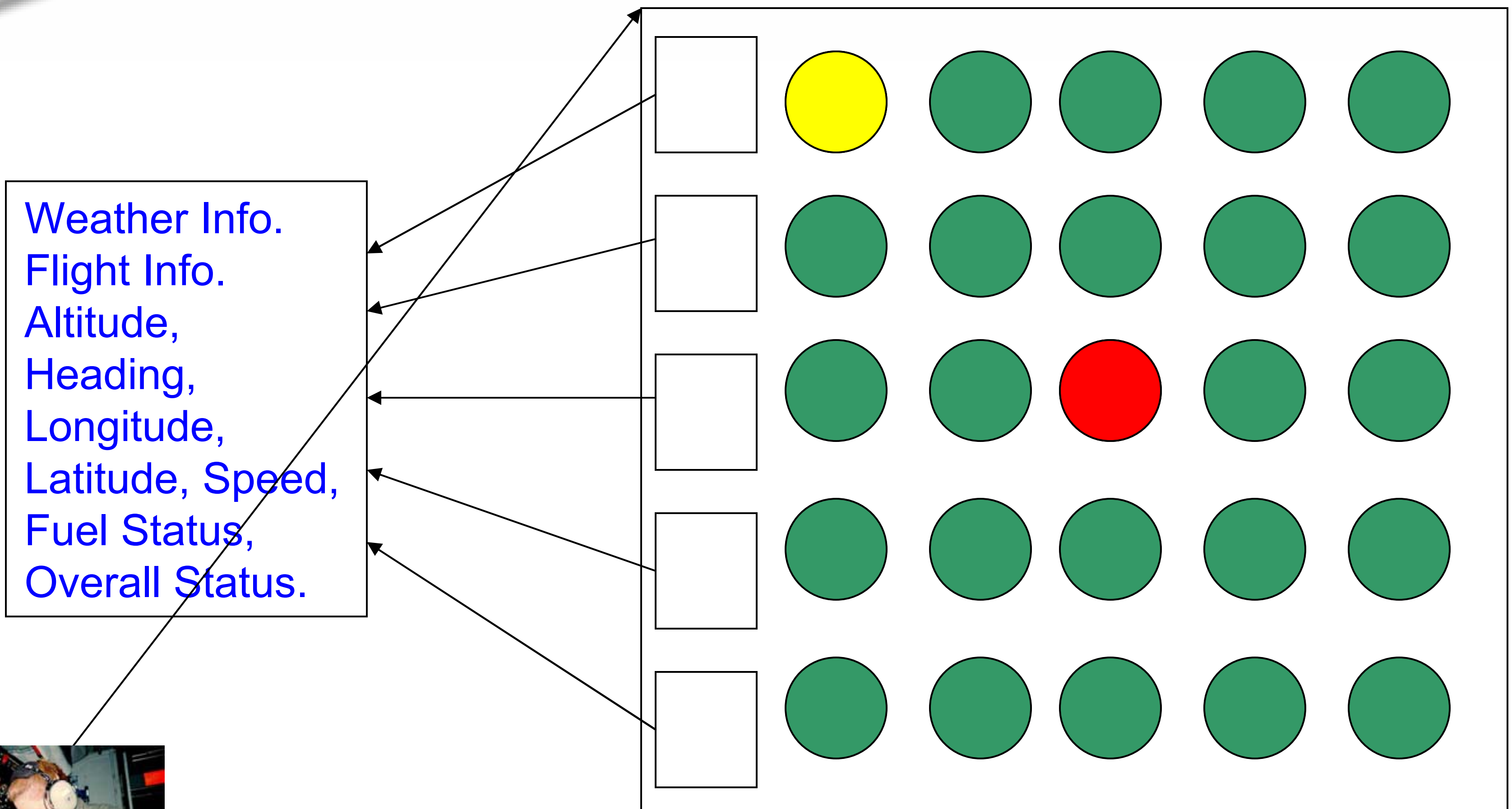
- **North Carolina**
  - Elizabethtown
- **South Carolina**
  - Georgetown

http://www.southcarolinapowerteam.com/custimage/DOC_SIS_New_Park.pdf, http://www.ncse.org/parks/colp2.htm, http://www.floridasgreatnorthwest.com/IndustrialParks/LeonParks.htm#ACC, http://www.franklineda.com/ind-park.html, http://www.ghcc.com/economic/infrastructure.asp

En Route IP Network Diagram



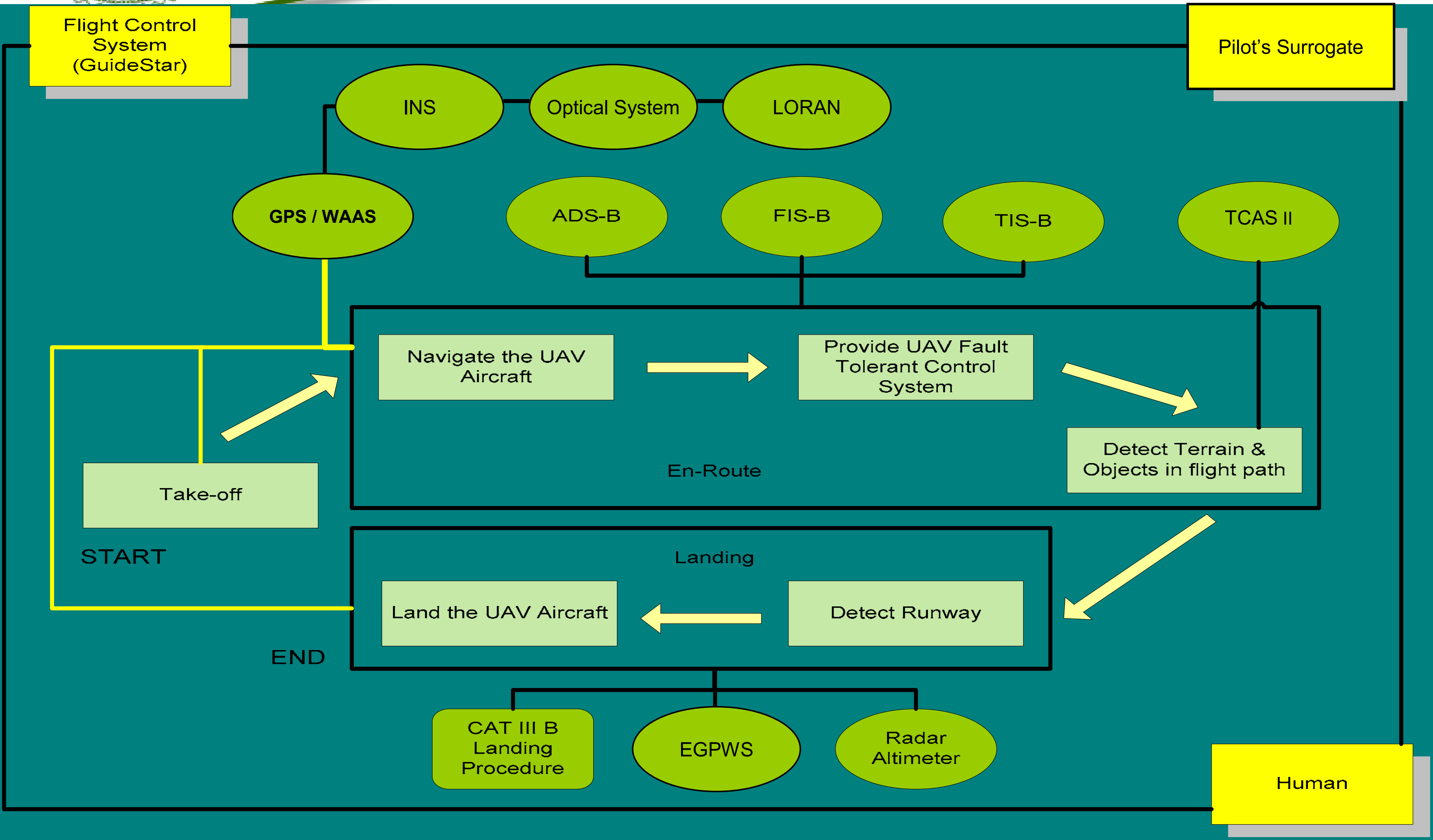
Human Operator/Ground Station



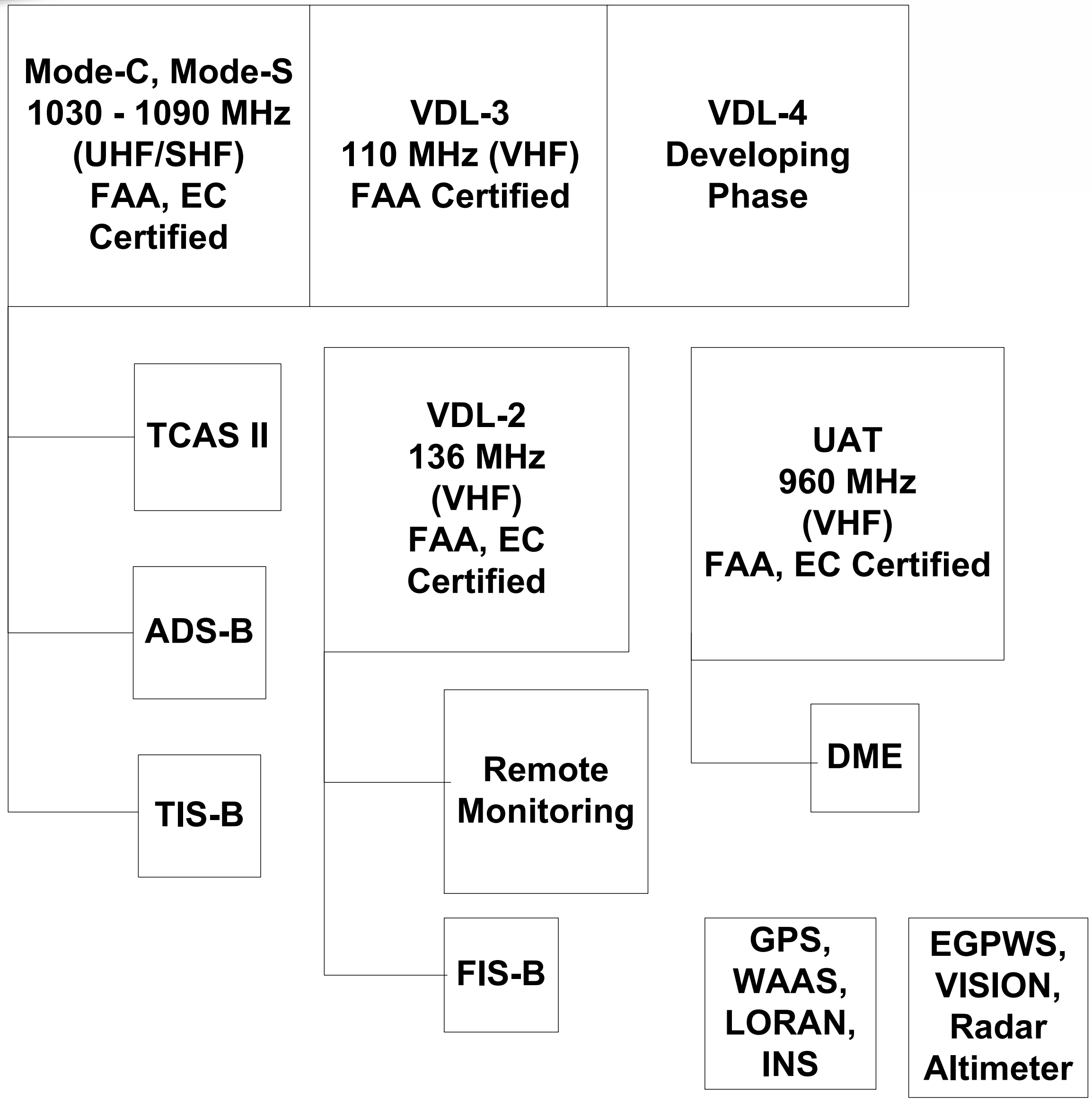
Reference: http://www.afrc.af.mil/hq/citamn/feb02/flighttestlarge.jpg

Avionics Architecture

Architecture

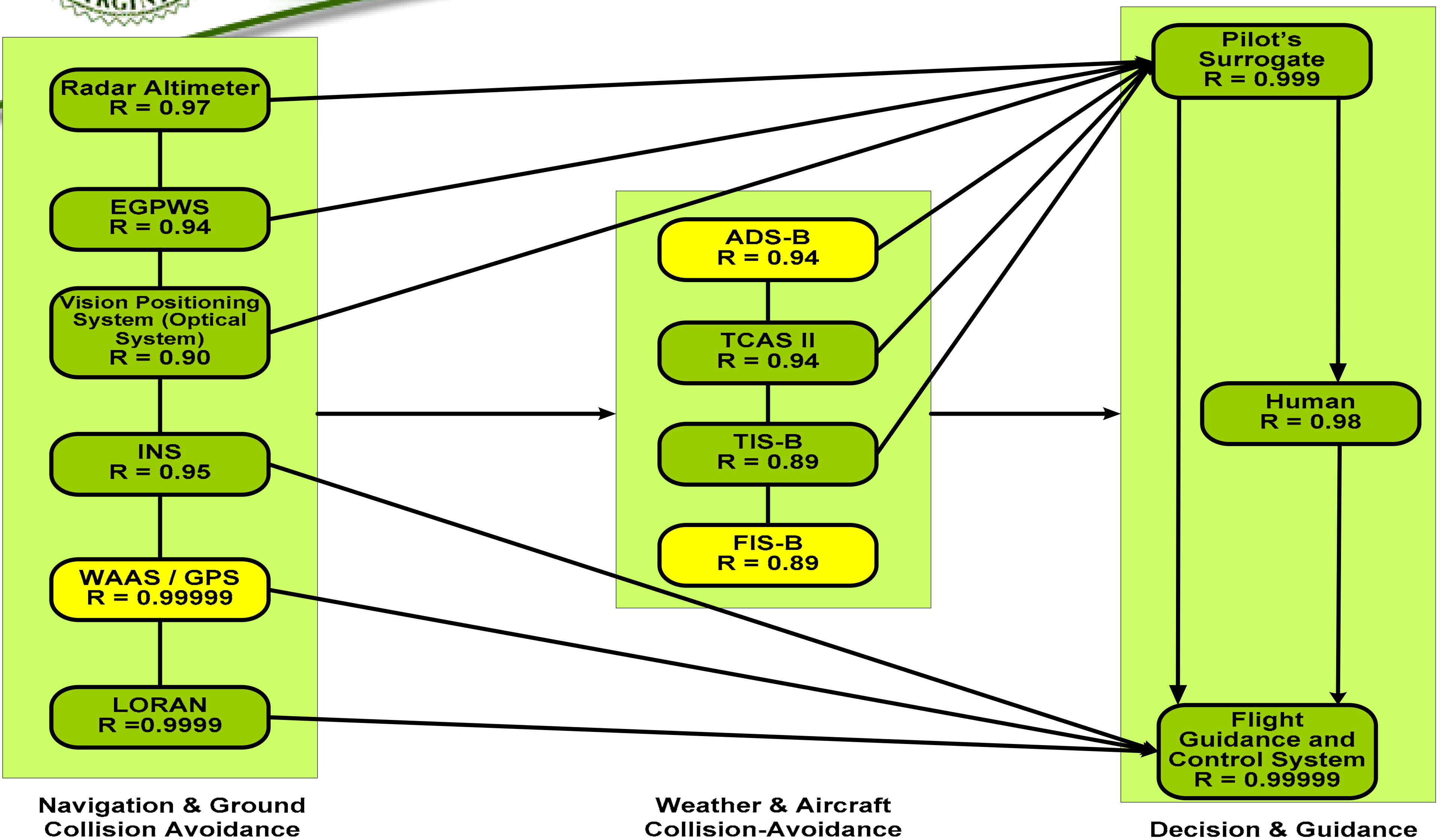


Data Links


Mode-C, Mode-S
1030 - 1090 MHz
(UHF/SHF)
FAA, EC
Certified
VDL-3
110 MHz (VHF)
FAA Certified
VDL-4
Developing
Phase
TCAS II
ADS-B
TIS-B
VDL-2
136 MHz
(VHF)
FAA, EC
Certified
Remote
Monitoring
FIS-B
UAT
960 MHz
(VHF)
FAA, EC Certified
DME
GPS,
WAAS,
LORAN,
INS
EGPWS,
VISION,
Radar
Altimeter

Reliability Analysis

Reliability Network

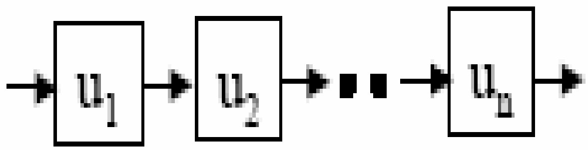


Diversity and Redundancy

Action / Data Links & Comps.	Landing	Collision Avoidance	Surveillance	Data Exchange	Navigation
VDL-2 (Remote Monitoring, FIS-B)				X	
VDL-3				X	
VDL-4 (FIS-B, ADS-B, Remote Monitoring)			X	X	
Mode-S (TCAS II, TIS-B, ADS-B)		X	X		
Enhanced Ground Proximity Warning System (EGPWS)	X	X			
Optical System (Vision)	X	X	X		X
LORAN Navigational System	X	X	X		X
Radio-Navigational System (GPS, INS, WAAS)	X	X	X		X

Calculation of Reliability

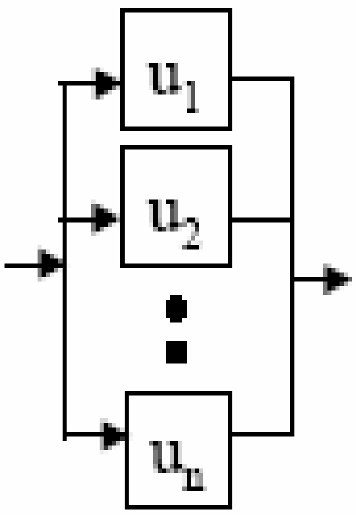
- For n units connected in series, the system is functioning if all the units are functioning, thus the reliability of the system is



$$R(t) = R_1(t)\, R_2(t) \ \dots\ R_n(t)$$

  – Critical system components can never be in series (single string)

- For n units connected in parallel, the system is functioning if at least one unit is functioning, thus system reliability is



$$R(t) = 1 - [1 - R_1(t)]\,[1 - R_2(t)] \ \dots\ [1 - R_n(t)]$$

Calculation of Reliability (cont'd)

- Let $R(t)$ be the reliability of a system and $Q(t) = 1 – R(t)$
- The average time between failure is

$$\text{MTBF} = 1/\lambda$$

where λ is the failure rate

- Reliability can be determined for each component using

$$R_n = e^{-(\lambda_n t)}$$

- Ex: System with 3 components

$$R^3 + 3R^2Q + 3RQ^2 + Q^3 = 1$$

where: R^3 represents all three components operating

Q^3 represents all three components failing

Component / Redundancies Variable Definitions

	Component / Redundancy
A	Radar Altimeter
B	EGPWS
C	Optical System
D	INS
E	WAAS / GPS
F	LORAN
G	ADS-B
H	TCAS II
I	TIS-B
J	FIS-B
X	Pilot's Surrogate
Y	Human
Z	Flight Control System (GuideStar™)

R = Reliability of each component / redundancy

Q = Failure of each component / redundancy

$R_{ABCDEF} = 1 - (1 - R_A)(1 - R_B)(1 - R_C)(1 - R_D)(1 - R_E)(1 - R_F)$

$R_{GHIJ} = 1 - (1 - R_G)(1 - R_H)(1 - R_I)(1 - R_J)$

$R_Z = R_Z$

$R_{XYZ} = 1 - (1 - R_X)(1 - R_Y)(1 - R_Z)$

System Reliability *with* Human Operator and Pilot's Surrogate

13 components - *with* Human Operator and Pilot's Surrogate

$$R^{13} + 13R^{12}Q + 78R^{11}Q^{2} + 286R^{10}Q^{3} + 715R^{9}Q^{4} + 1267R^{8}Q^{5} + 1656R^{7}Q^{6} + 1656R^{6}Q^{7} + 1267R^{5}Q^{8} + 715R^{4}Q^{9} + 286R^{3}Q^{10} + 78R^{2}Q^{11} + 13RQ^{12} + Q^{13} = 1 = \text{Reliability}$$

Reliability of Entire System

$R_{ABCDEF} * R_{GHIJ} * R_{XYZ} = 99.99\ \%$

Simulation and Analysis Results

Results

- System Reliability Analysis
  - Overall System Reliability with Human Operator & Pilot Surrogate = 99.99%
  - At least triple redundancies in each UAVs Operational Criteria such as Navigation, Collision Avoidance and Surveillance which provide the robust, fail soft, and very high reliability
- Landing Simulation
  - None UAVs Superseded by Human Operator
  - 2% Redirected UAVs
  - Ground roll ~ 2400feet

En-Route Simulation Results

	Number of UAVs per Industrial Park	Time (hours)	Success Delivery	UAV Utilization	Number of Hours Flown per UAV
1 Service Request per city per hour in average	2	720	94%	0.798	575
		2400	95%	0.766	1838
	3	**720**	**99%**	**0.802**	**577**
		2400	99%	0.764	1834
2 Service Requests per city per hour in average	3	720	89%	0.868	625
		2400	92%	0.846	2030
	5	**720**	**99%**	**0.894**	**644**
		2400	98%	0.896	2150
3 Service Requests per city per hour in average	5	720	91%	0.914	658
		2400	94%	0.898	2155
	9	**720**	**99%**	**0.902**	**649**
		2400	**99%**	**0.904**	**2170**

Business Case Analysis Results

Break Even with 25 Planes

Breakeven Analysis

UAV CARGO SYSTEM

Amounts shown in U.S. dollars

Sales		
Sales price per unit	600.00	
Sales volume per period (units)	83,760	
Total Sales		50,256,000.00
Variable Costs		
Variable costs per unit	388.91	
Total Variable Costs		32,574,713.76
Unit contribution margin	211.09	
Gross Margin		17,681,286.24
Fixed Costs Per Period		
Total Fixed Costs per period		14,724,059.00
Net Profit (Loss)		2,957,227.24

Results:

Breakeven Point (units): 69,751

Sales volume analysis:

	Year 1	Year 2	Year 3	Year 4	Year 5
Sales volume per period (units)	16,752	33,504	50,256	67,008	83,760
Sales price per unit	600.00	600.00	600.00	600.00	600.00
Fixed costs per period	14,724,059.00	14,724,059.00	14,724,059.00	14,724,059.00	14,724,059.00
Variable costs	6,514,942.75	13,029,885.50	19,544,828.26	26,059,771.01	32,574,713.76
Total costs	21,239,001.75	27,753,944.50	34,268,887.26	40,783,830.01	47,298,772.76
Total sales	10,051,200.00	20,102,400.00	30,153,600.00	40,204,800.00	50,256,000.00
Net profit (loss)	(11,187,801.75)	(7,651,544.50)	(4,115,287.26)	(579,030.01)	2,957,227.24

Cost Analysis

- Recurring costs are low and Fixed costs are very high, due to:
  - implementation of state-of-the-art technology components and compensating for not having a pilot
- High variable costs make operation expensive
- Return On Investment
  - About 5 years

Conclusion

- Reliability of the System
- Feasibility of UAV Cargo System Concept
- Business Case
- Usage of Spiral Development
- Possible Complementary Usages

Acknowledgements

- **Dr. Herman Rediess**

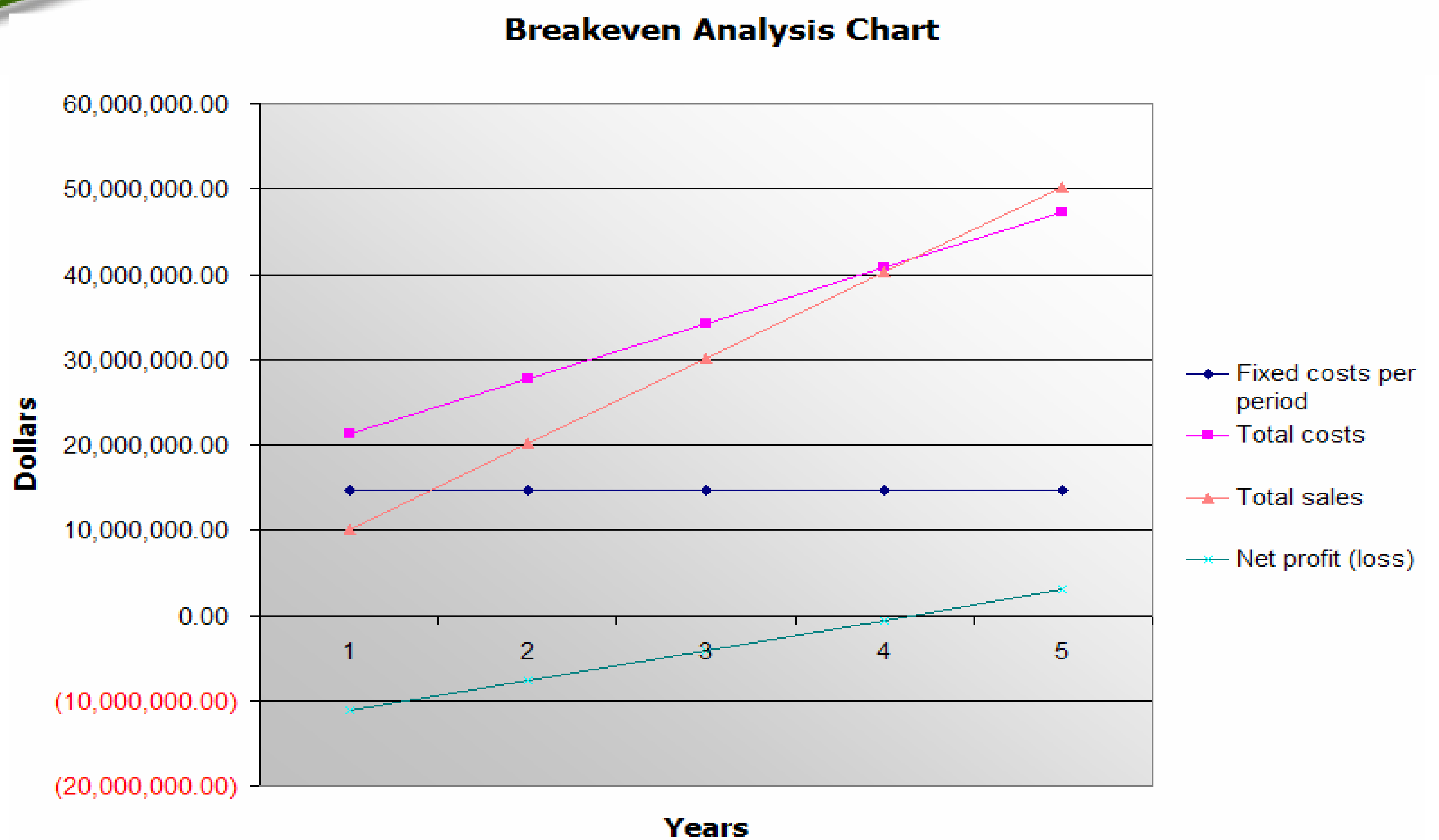
  Director of Aviation Research, Federal Aviation Administration
- **Dr. Lance Sherry**

  Research Assistant, George Mason University and Former Director of Business Development, Athena Technologies, Inc.
- **Dr. George Donohue**

  Professor of Systems Engineering and Operations Research, George Mason University

Questions ?

Break Even with 25 Planes



Cost Recommendations

- Buy vs. lease of equipment
- Break even point considering:
  - High equipment costs as a barrier to entry
  - Economies of scale of larger operations
  - Decreasing cost of technology over time
  - Government subsidies made in the public interest
- Financially feasible over time
  - Number of Operator vs. Number of UAVs
  - More Cargo Service Request Characteristics

Break Even with 45 Planes

Breakeven Analysis

UAV CARGO SYSTEM

Amounts shown in U.S. dollars

Sales		
Sales price per unit	600.00	
Sales volume per period (units)	141,948	
Total Sales		85,168,800.00
Variable Costs		
Variable costs per unit	416.77	
Total Variable Costs		59,159,178.14
Unit contribution margin	183.23	
Gross Margin		26,009,621.86
Fixed Costs Per Period		
Total Fixed Costs per period		22,764,682.20
Net Profit (Loss)		3,244,939.66

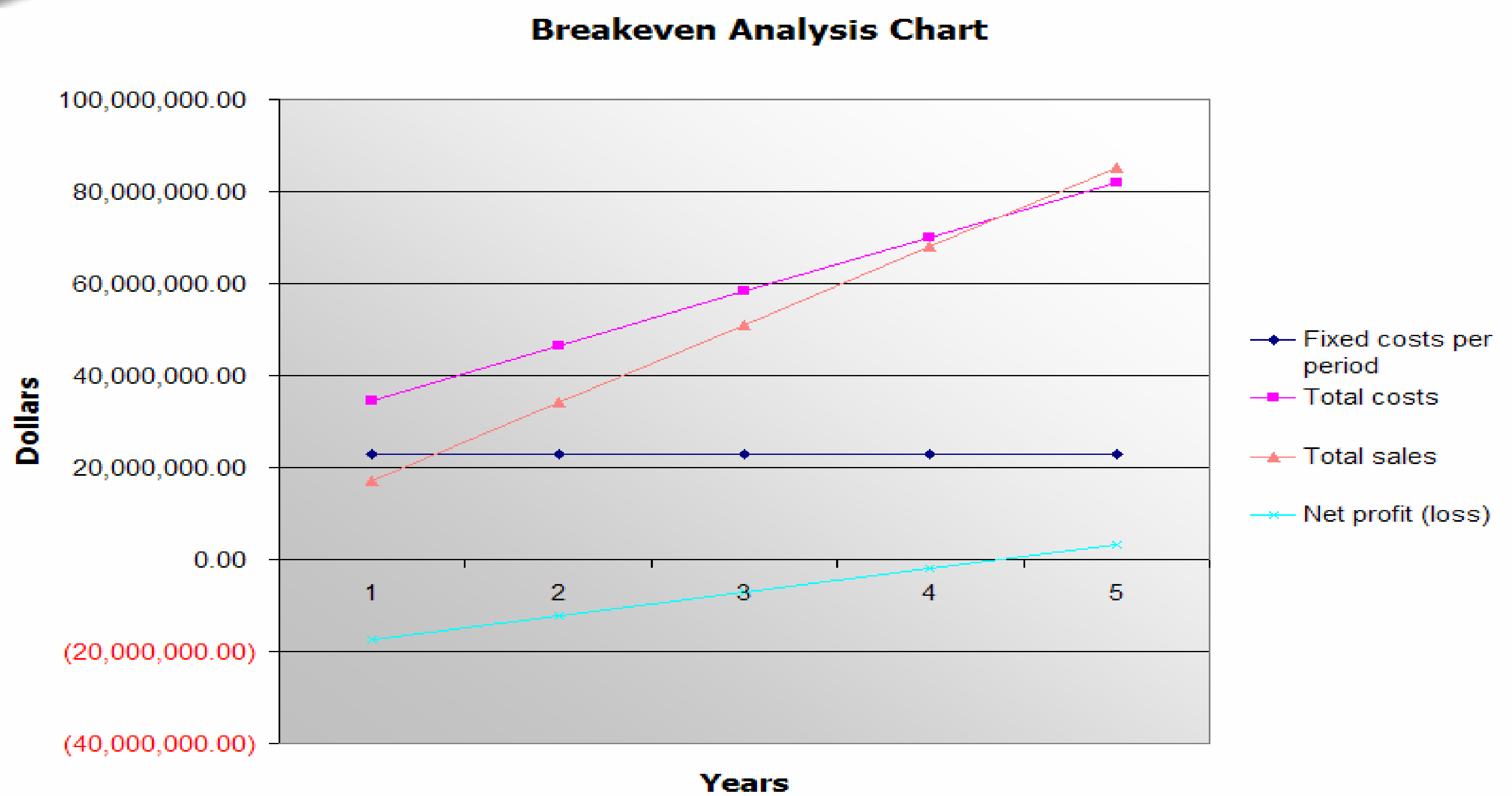
Results:

Breakeven Point (units): **124,239**

Sales volume analysis:

	Year 1	Year 2	Year 3	Year 4	Year 5
Sales volume per period (units)	28,390	56,779	85,169	113,558	141,948
Sales price per unit	600.00	600.00	600.00	600.00	600.00
Fixed costs per period	22,764,682.20	22,764,682.20	22,764,682.20	22,764,682.20	22,764,682.20
Variable costs	11,831,835.63	23,663,671.26	35,495,506.89	47,327,342.52	59,159,178.14
Total costs	34,596,517.83	46,428,353.46	58,260,189.09	70,092,024.72	81,923,860.34
Total sales	17,033,760.00	34,067,520.00	51,101,280.00	68,135,040.00	85,168,800.00
Net profit (loss)	(17,562,757.83)	(12,360,833.46)	(7,158,909.09)	(1,956,984.72)	3,244,939.66

Break Even with 45 Planes



Flight Control & Weather

- **Flight Control Guidance System**
  - Interpreting sensor data and making decisions about navigating the airplane
  - Ability to detect and isolate failure part (s), reconfigure aircraft to continue flying without the failed part (s)
- **FIS-B** (Flight Information Service Broadcast)
  - Weather Condition and Provide Icing Altitude

Concept of Operations

- Size of the Industrial Park (IP)
- Surrogate Plane
- Hypothetical Situation
- Central Operation Center - Human Operator and Interface
- Possible Rare Normal and Abnormal Situation

Surrogate Plane Specs

- Performance Specification
  - **Certified Ceiling ft/m** 25,000/7,620
  - **Cruise Speed (10,000 ft)** knts/km 184/341
  - **Stall Speed (Ldg) knts/km** 61/113
  - **Take off S.L. ISA** Ground Roll ft/m 1,365/416 (50-ft Obs. ft/m 2,420/738)
  - **Landing S.L.** Ground Roll ft/m 950/290 (50-ft. Obs. ft/m 1,795/547)
  - **Maximum Useful Load**
    - 3,500 lbs for 100 miles trip
    - 1,500 lbs for 900 miles trip

Navigation

- **WAAS** (Wide Area Augmentation System) / GPS
  - Provides correction and integrity signals for standard GPS signals
- **LORAN** (LOng-range Radio Aid to Navigation system)
  - A long-range radio navigation position-fixing system consisting of an array of fixed stations that transmit precisely synchronized signals to mobile receivers.
- **INS** (Inertial Navigational System)
  - Backup for the GPS
- **Vision Position System** (Optical System)
  - Calculates the Altitude to Runway and Surveillance of the Surroundings

Break Even with 15 Planes

Breakeven Analysis 15 Planes

UAV CARGO SYSTEM

Amounts shown in U.S. dollars

Sales		
Sales price per unit	650.00	
Sales volume per period (units)	42,300	
Total Sales		27,495,000.00
Variable Costs		
Variable costs per unit	414.50	
Total Variable Costs		17,533,503.65
Unit contribution margin	235.50	
Gross Margin		9,961,496.35
Fixed Costs Per Period		
Total Fixed Costs per period		9,758,627.40
Net Profit (Loss)		202,868.95

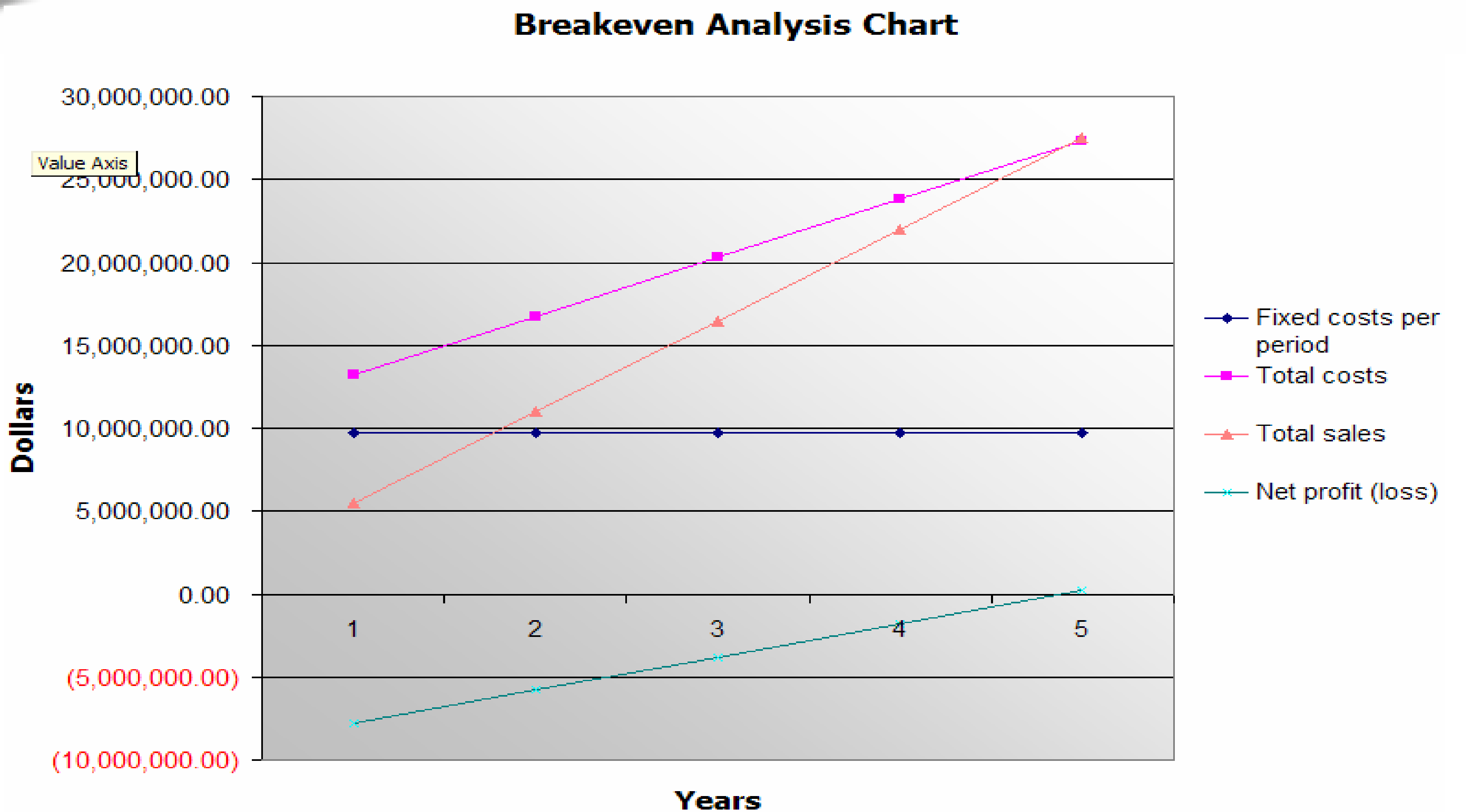
Results:

Breakeven Point (units): 41,439

Sales volume analysis:

	Year 1	Year 2	Year 3	Year 4	Year 5
Sales volume per period (units)	8,460	16,920	25,380	33,840	42,300
Sales price per unit	650.00	650.00	650.00	650.00	650.00
Fixed costs per period	9,758,627.40	9,758,627.40	9,758,627.40	9,758,627.40	9,758,627.40
Variable costs	3,506,700.73	7,013,401.46	10,520,102.19	14,026,802.92	17,533,503.65
Total costs	13,265,328.13	16,772,028.86	20,278,729.59	23,785,430.32	27,292,131.05
Total sales	5,499,000.00	10,998,000.00	16,497,000.00	21,996,000.00	27,495,000.00
Net profit (loss)	(7,766,328.13)	(5,774,028.86)	(3,781,729.59)	(1,789,430.32)	202,868.95

Break Even with 15 Planes



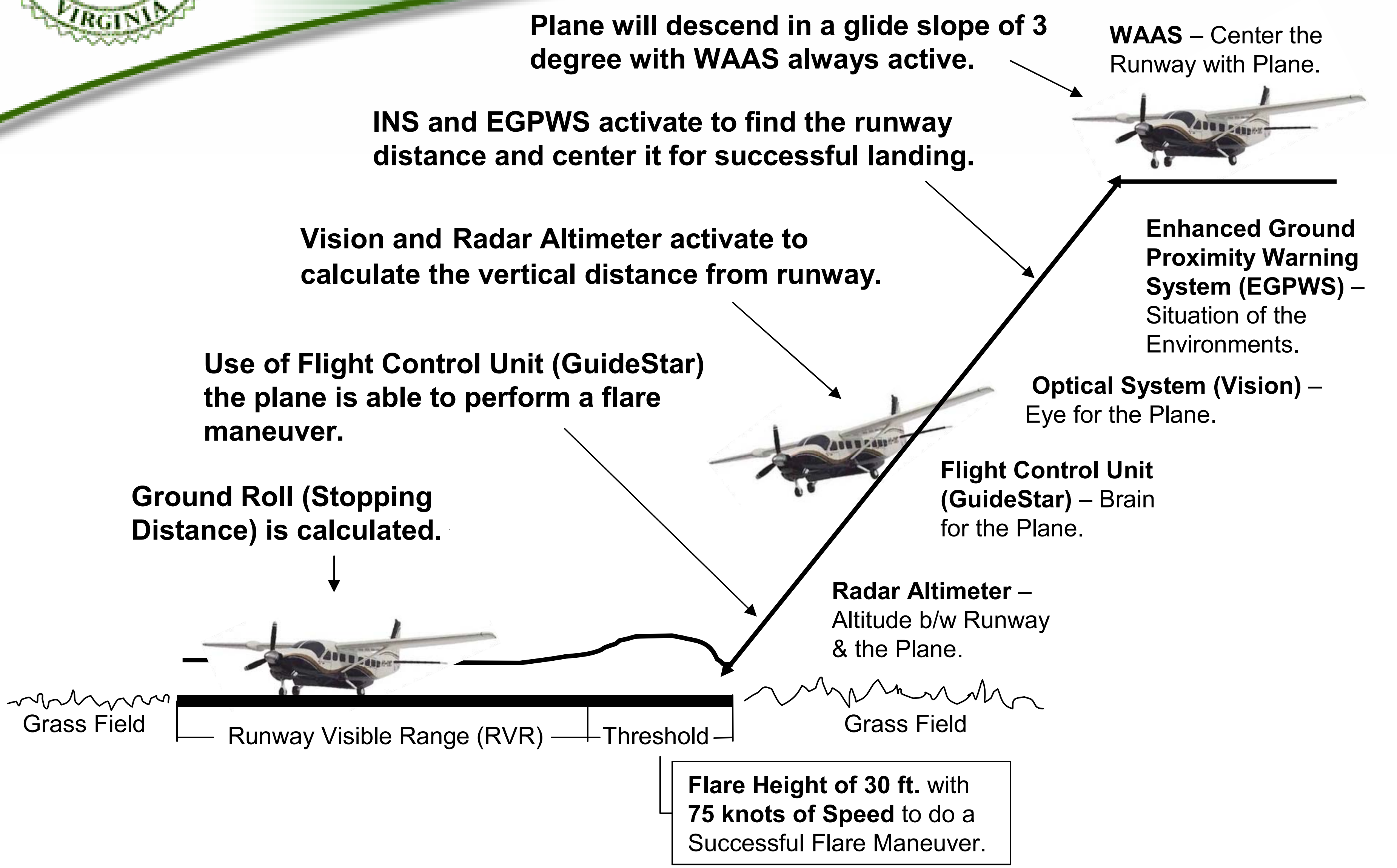
Collision Avoidance & Surveillance

- **ADS-B** (Automatic Dependant Surveillance Broadcast)
  - Navigation State Vector Surveillance
- **TIS-B** (Traffic Information Service Broadcast)
  - Air and Ground Collision Avoidance
- **TCAS II** (Traffic Collision Avoidance System)
  - Last Resort Air Collision Avoidance System
- **EGPWS** (Enhanced Ground Proximity Warning System)
  - Terrain awareness and alerting system
- **Radar Altimeter**
  - Terrain Collision Avoidance & Measures the height of the main wheels above touchdown

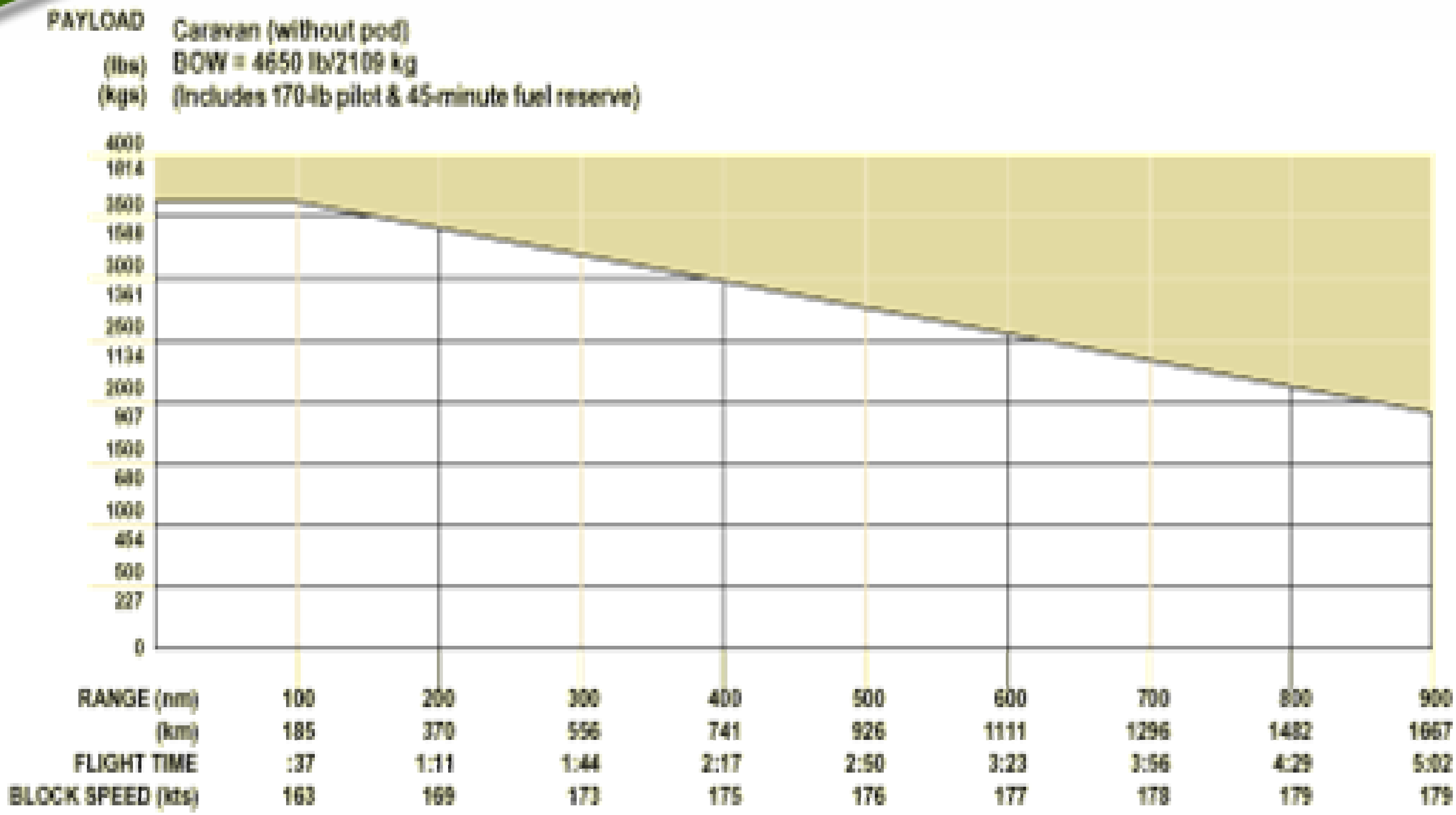
Additional Data Links

- **VDL:** Digital data link that operate in the VHF frequency band:
  - **Mode 2**: Data, 31.5 Kb, Carrier Sense Multiple Access (CSMA) technology
  - **Mode 3**: Voice and data, 31.5 Kb, Time Division Multiple Access (TDMA) technology
  - **Mode 4**: Data, 19.5 Kb, TDMA technology with self-organizing function (STDMA)
- **Mode-S**: Data, CSMA, 2 Mbits, 1090/1030 MHz (UHF/SHF)

Landing Sequence



CONOP Parameters



Rare Normal Scenario

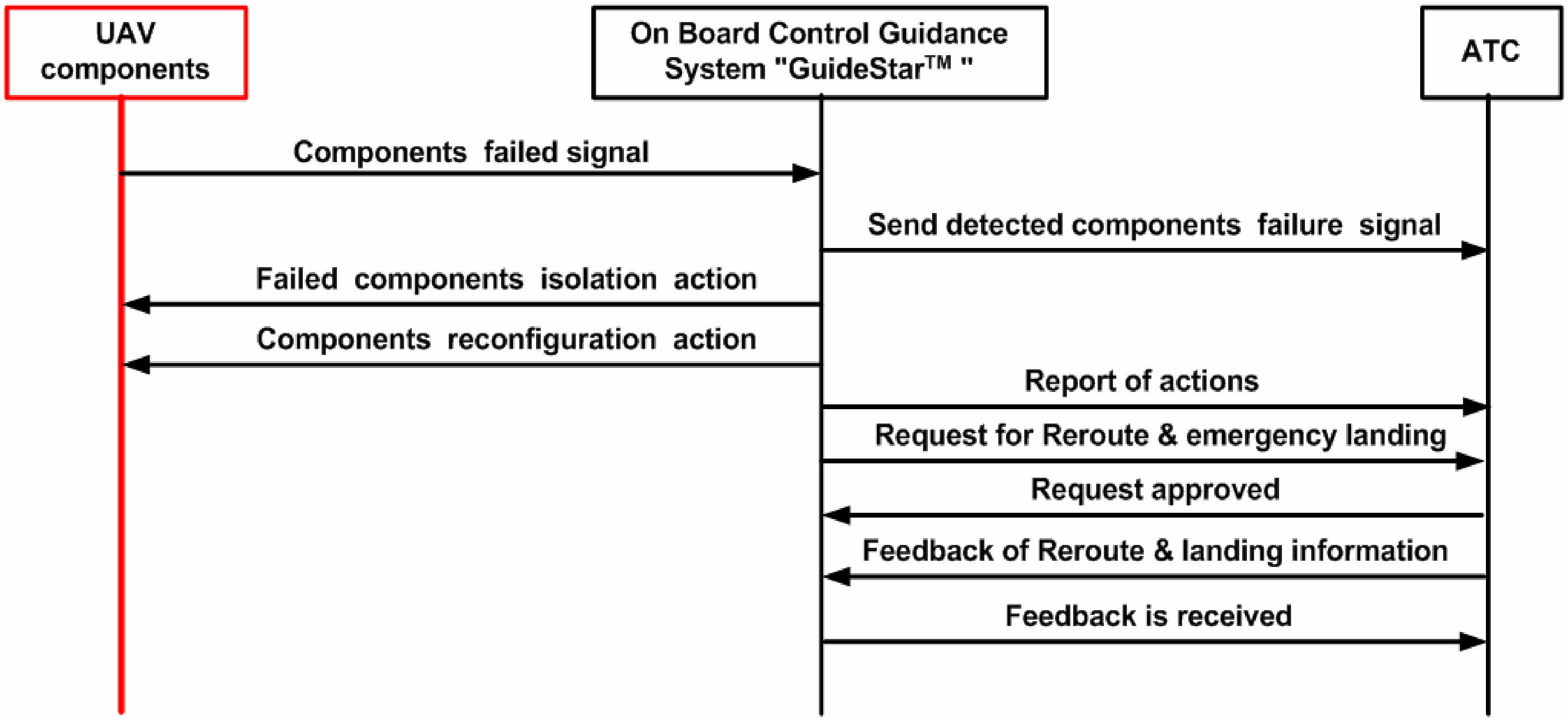


Figure 7. Rare Normal Scenario – when some of UAV components have failed

Utility Function

- **UAV Cargo System Utility Function Questionnaire**
- How much would you pay to reduce the cost of the system? Example: Would pay $10M to improve the cost from $20M to $8M.

Dollar Amount: $6M < $ Optimal < $10M

Cost	Value Score
$4 M	100
$6 M	70
$8 M	30
$10 M	0

- How much would you pay to improve the operational performance of the system?

Optimal Hours Amount: 8 Hrs/day to deliver

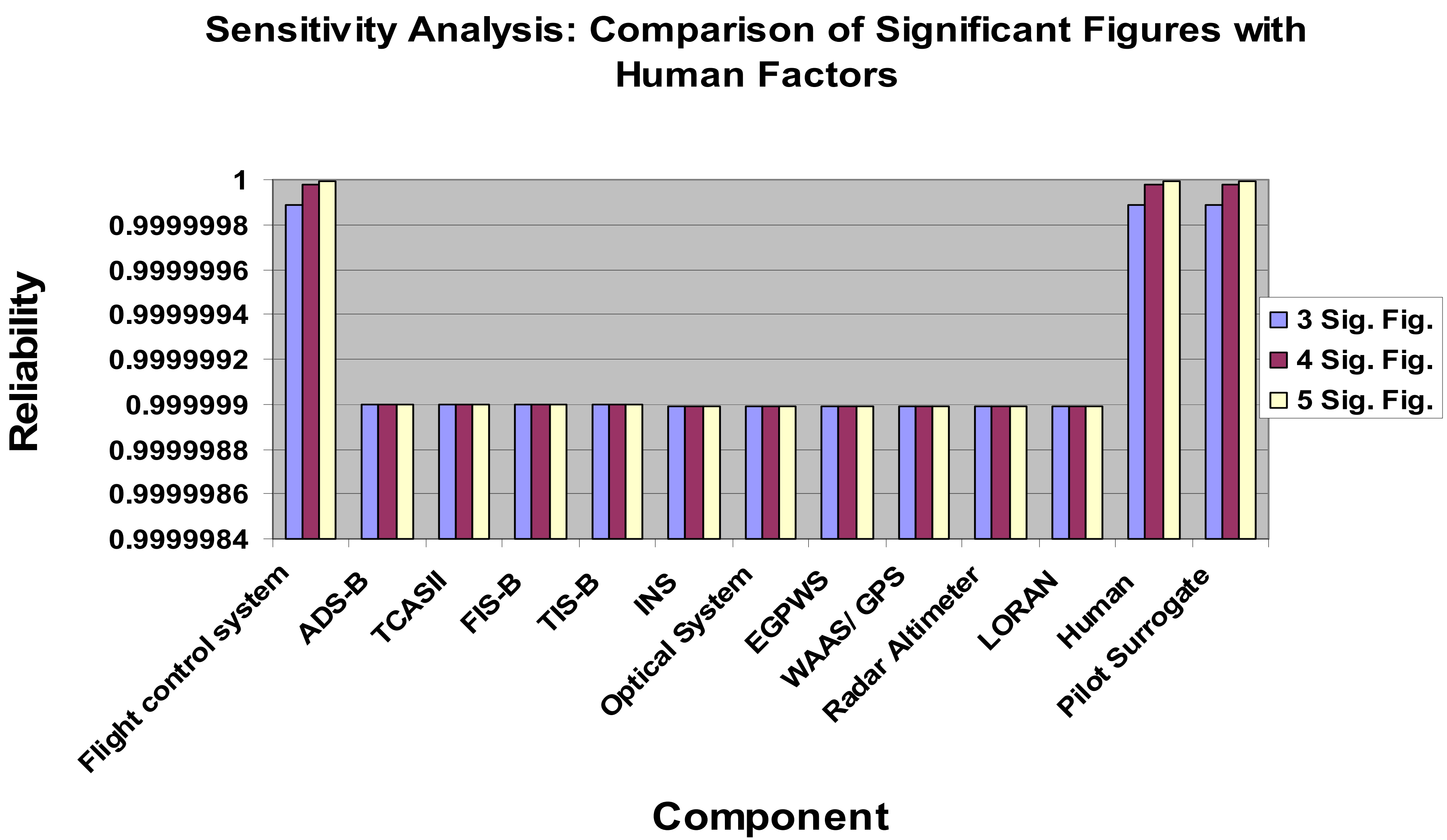
Operational Performance	Value Score
8 hrs/day	100
12 hrs/day	50
24 hrs/day	0

- How much would you pay to increase the safety of the system?

Optimal Reliability Amount: 99.999% Reliability

Safety	Value Score
99.999% reliable	100
99.99% reliable	95
99.9% reliable	50
98% reliable	0

Sensitivity Analysis



Pilot's Surrogate

Utilizes sensor fusion and guidance technologies enabling the optimal blending of redundant sensors during the various phases of a mission, and the generation of appropriate guidance commands for steering the vehicle.

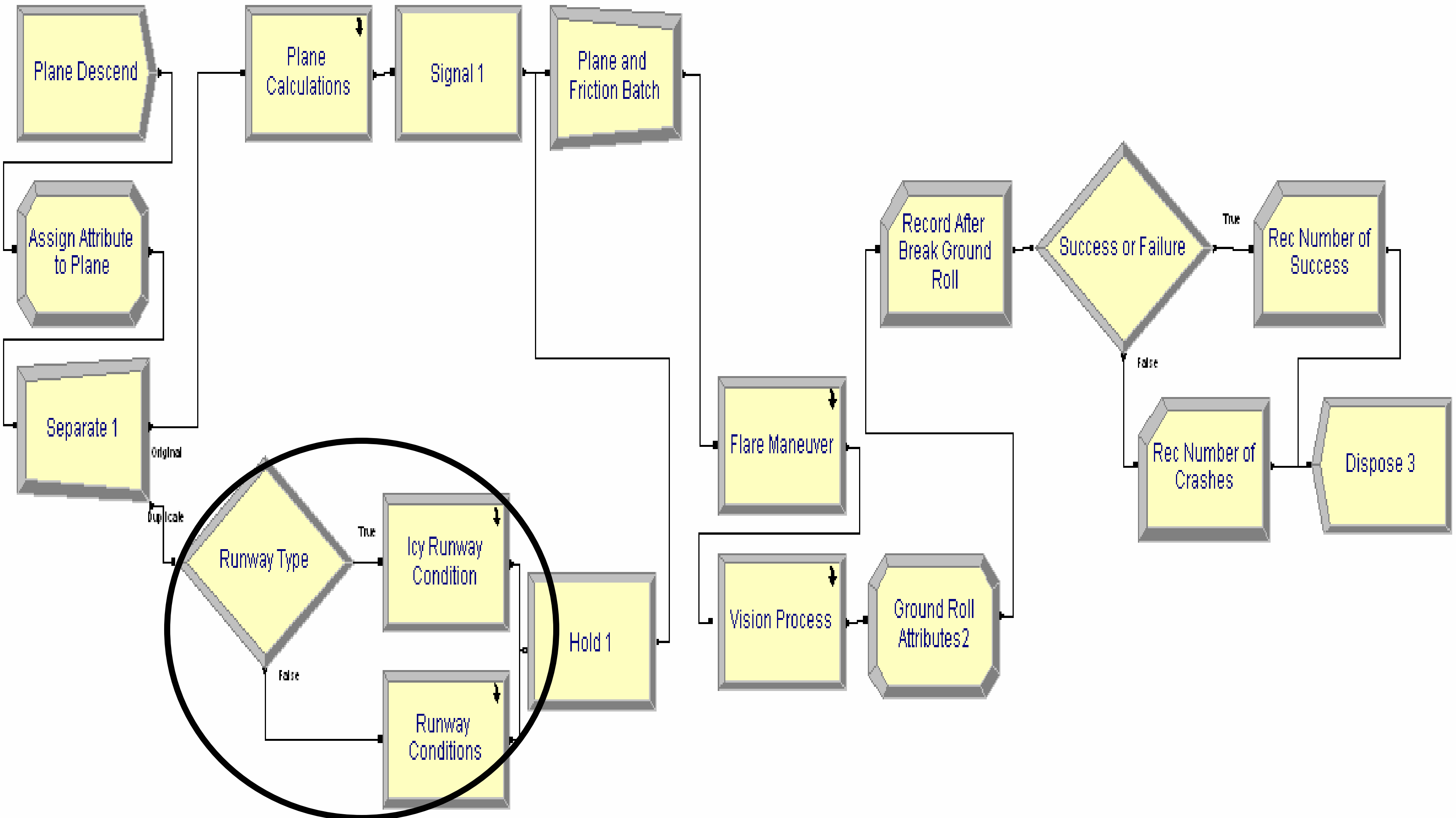
Collision Avoidance Sensors

Optical System
EGPWS
Radar Altimeter

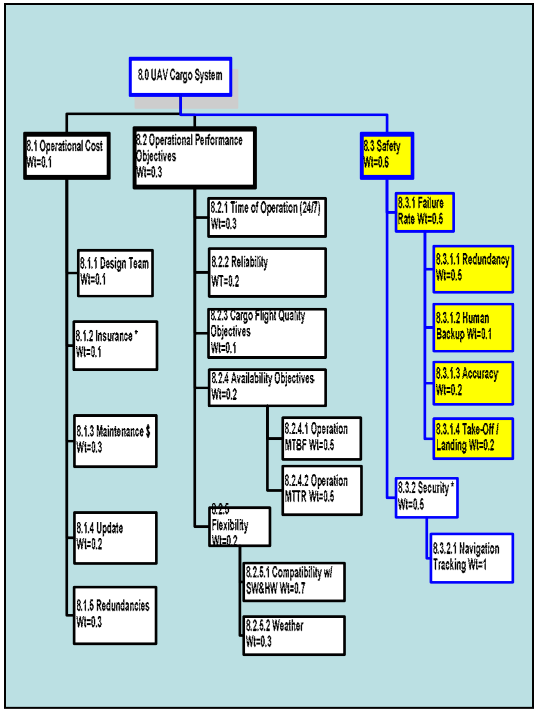
ADS-B
TIS-B
TCAS II

Voting Algorithm

ARENA Simulation



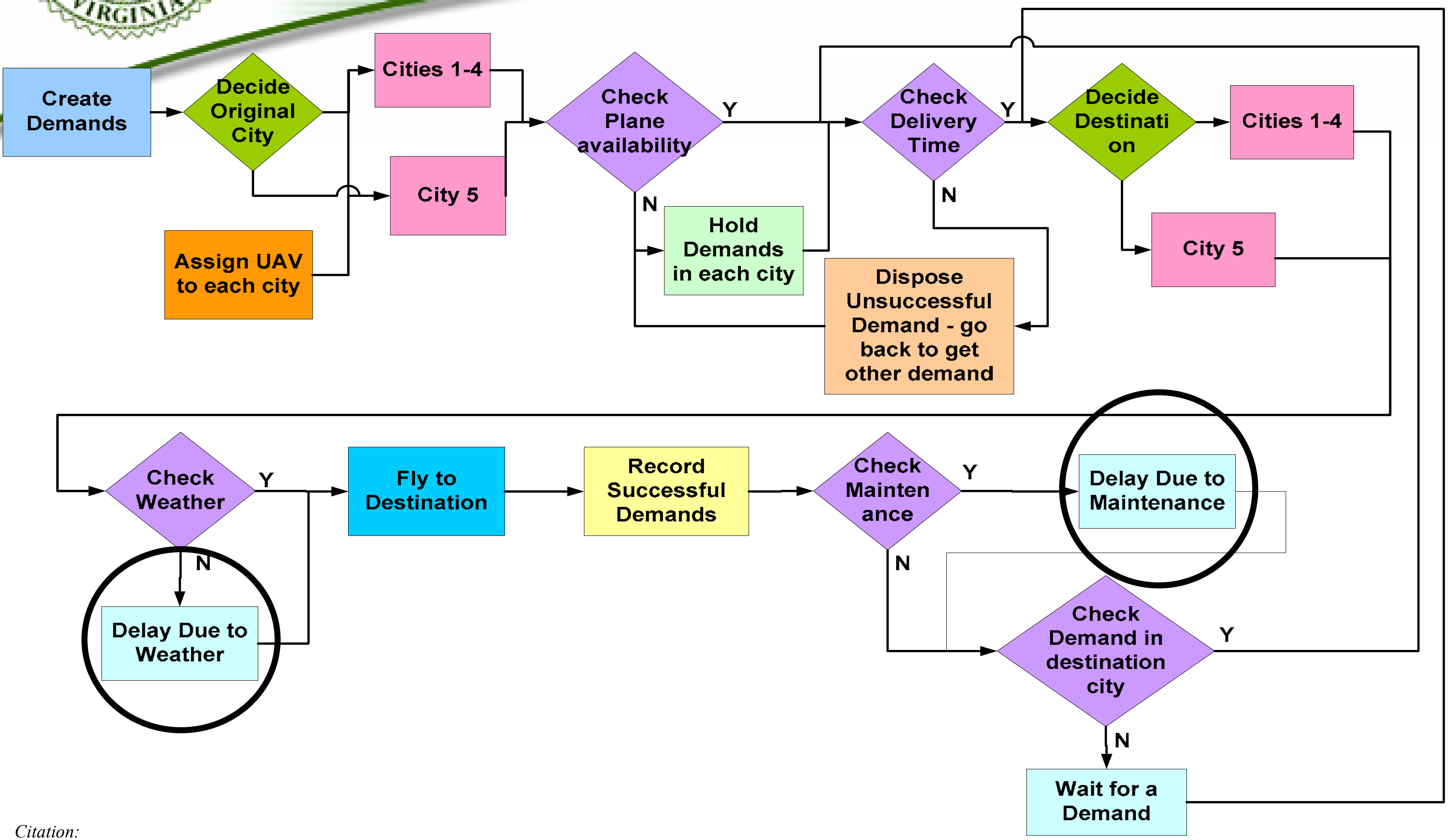
Detailed Value Hierarchy



- 8.0 UAV Cargo System
  - 8.3 Max. Safety Wt=0.6
    - 8.3.1 Failure Rate Wt=0.5
      - 8.3.1.1 Redundancy Wt=0.5
      - 8.3.1.2 Human Backup Wt=0.1
      - 8.3.1.3 Accuracy Wt=0.2
      - 8.3.1.4 Take-Off / Landing Wt=0.2
    - 8.3.2 Security * Wt=0.5
      - 8.3.2.1 Navigation Tracking Wt=1

* Out of Scope

ARENA Simulation Logic



Citation:

Trani, Antonio. SATSLab, Virginia Tech. Pg 232. "Transportation System Baseline Assessment Study". Revision 1.0, May 30, 2002.

Surrogate Plane Specs

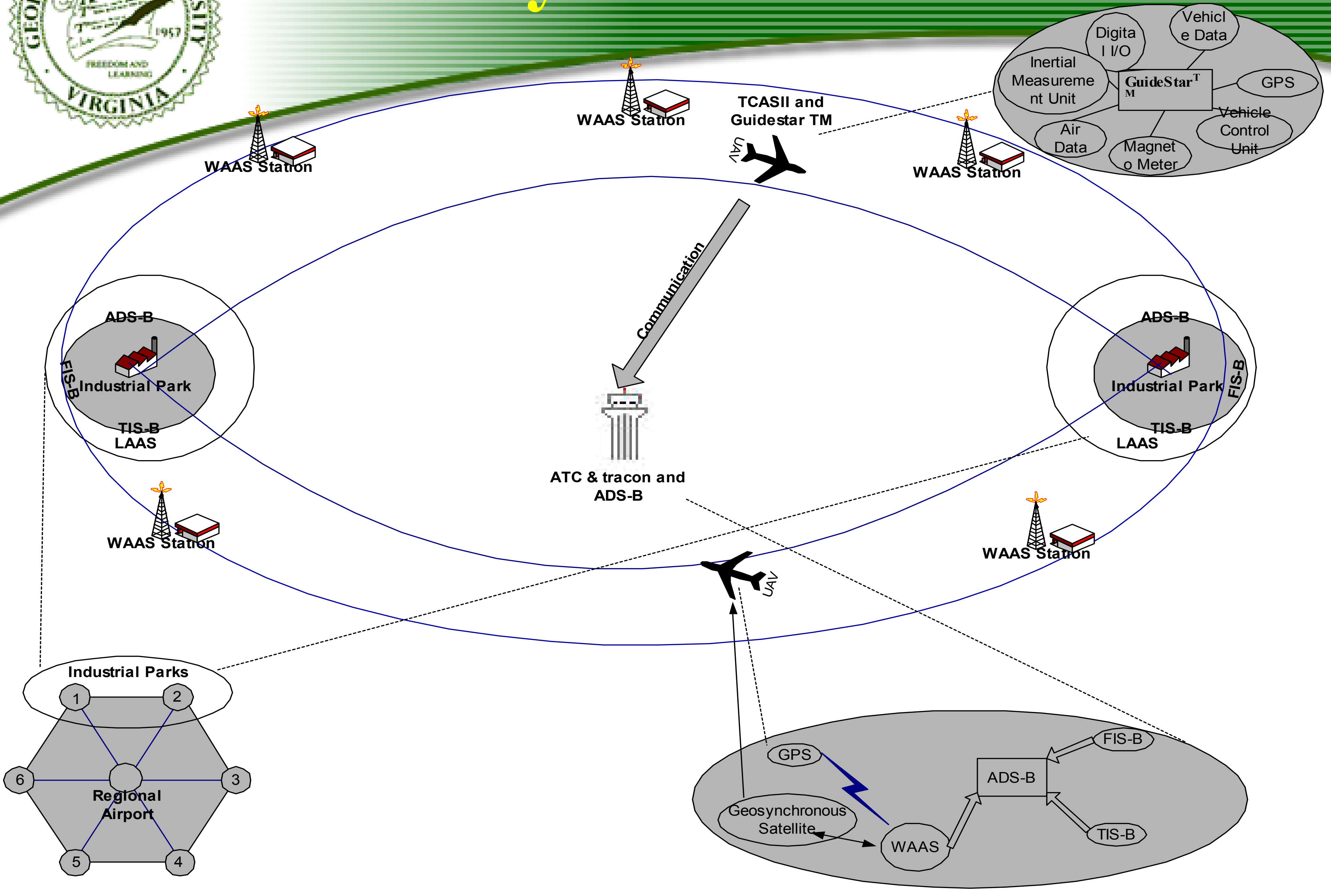
- Performance Specification
  - **Certified Ceiling ft/m** 25,000/7,620
  - **Cruise Speed (10,000 ft)** knts/km 184/341
  - **Stall Speed (Ldg) knts/km** 61/113
  - **Takeoff S.L. ISA** Ground Roll ft/m 1,365/416 (50-ft Obs. ft/m 2,420/738)
  - **Landing S.L.** Ground Roll ft/m 950/290 (50-ft. Obs. ft/m 1,795/547)
  - **Maximum Useful Load** ~ 3,500 lbs for 100 miles trip
  - **Maximum Weights lbs/kg** Ramp 8,785/3,985
  - **Standard Empty Weight lbs/kg** 4,285/1,944

Parameters

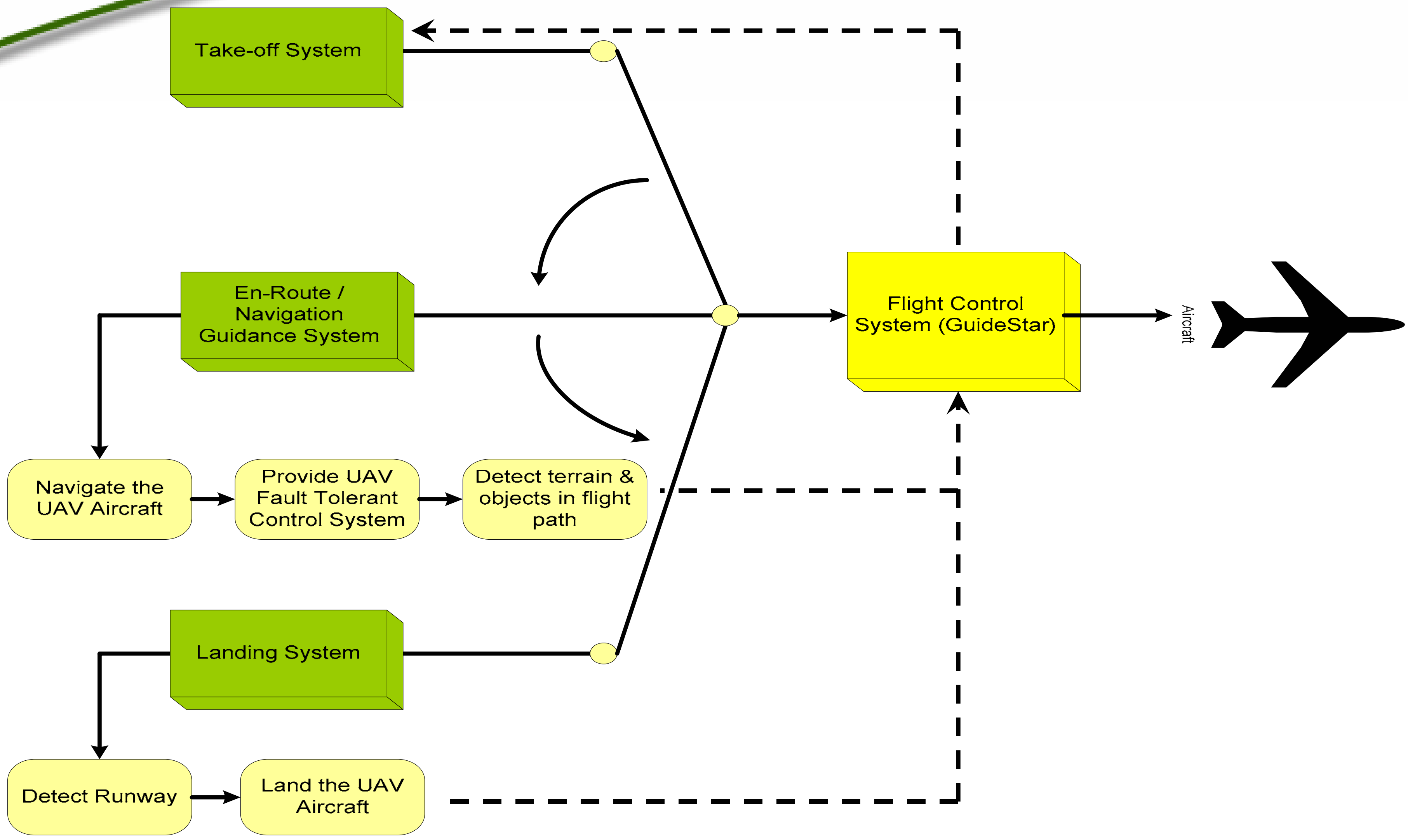
- Individual reliability, MTBF, and availability of components are set by manufacturing specifications

- A collection of *n components* related to the UAV system

System Overview



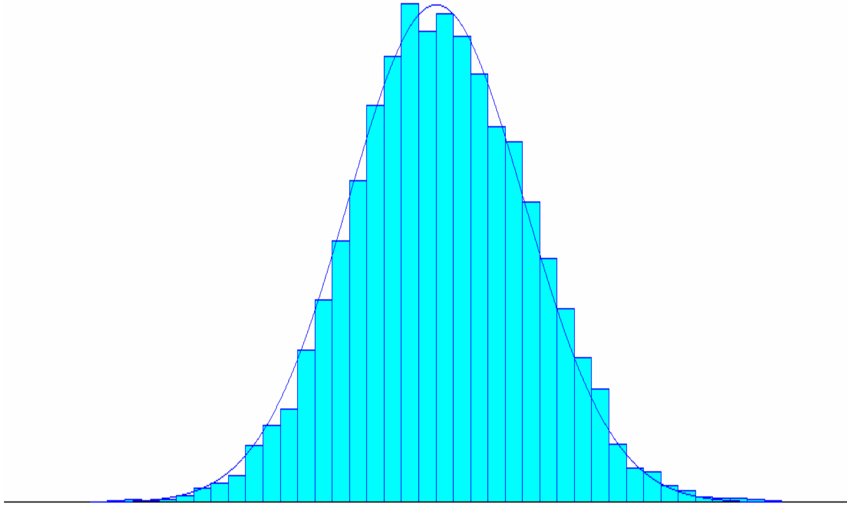
Flow Diagram – Flight Process



Statistical Distributions

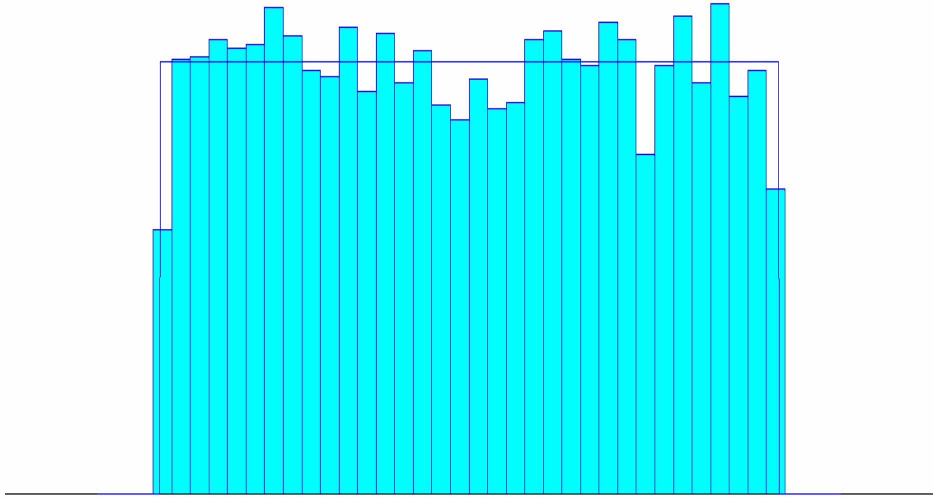
Runway Condition

– Icy Condition Friction:



NORM(0.0826, 1.27)

– Dry and Wet Condition Friction:



UNIF(.5,.8)

Wet Dry

Citation:

Trani, Antonio. SATSLab, Virginia Tech. Pg 232. "Transportation System Baseline Assessment Study". Revision 1.0, May 30, 2002.

Statistical Distributions

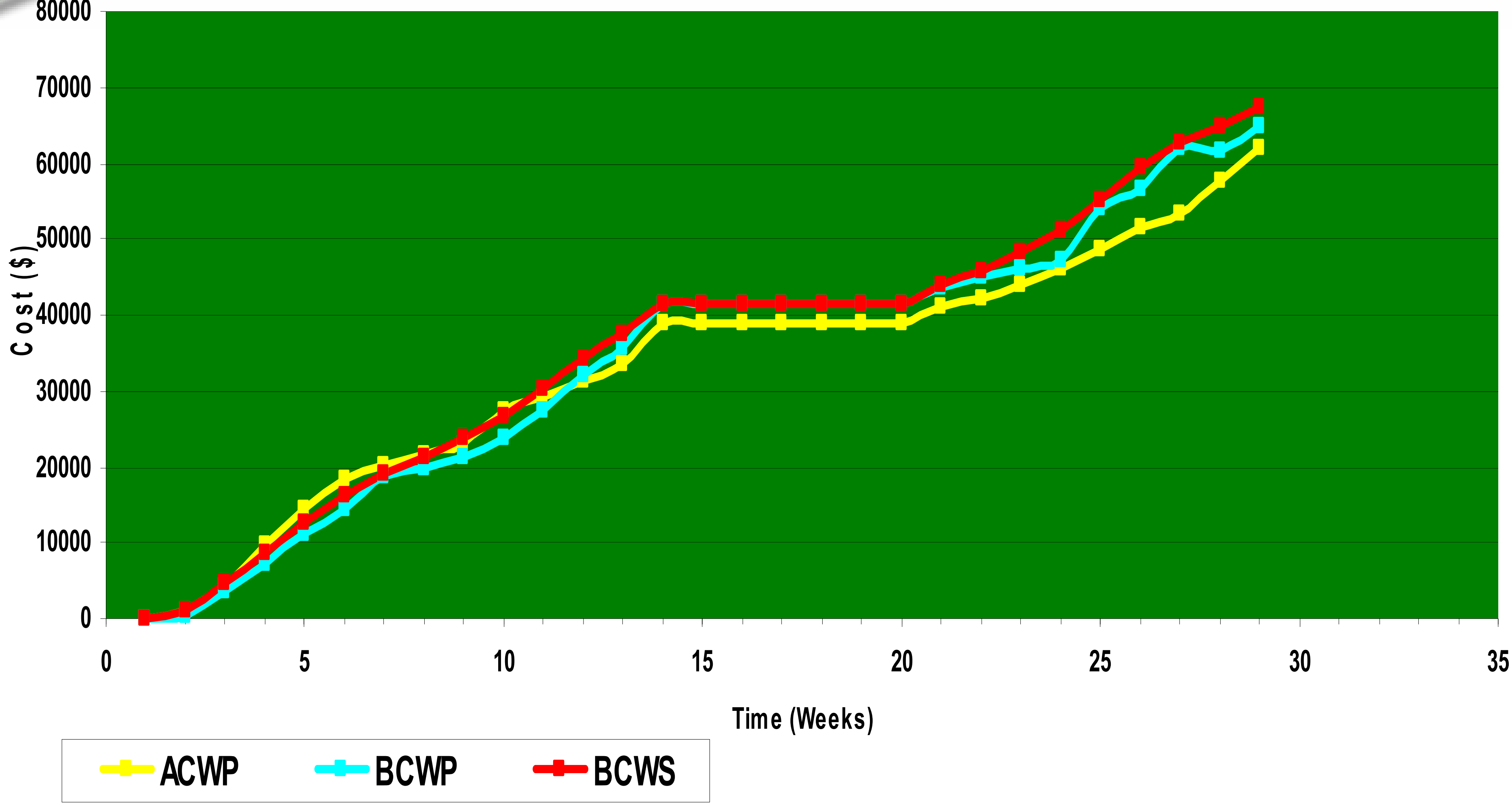
- Time of arrival =
  - Triangular Distribution (15, 30, 40)
- Entities / arrival =
  - Uniform Distribution (1, 5)
- Delay time for Loading & Unloading =
  - Gamma Distribution (beta = 7.7, alpha = 1.6)
- Delay time for Maintenance (100 Hrs) =
  - Weibull Distribution (beta = 12.2, Std. Dev = 1.98)
- Delay time for Weather =
  - Normal Distribution (mean = 46, Std. Dev = 9)

Estimated Simulation Hours

- To Date:
  - 150 Hours x $20.00 = $3,000.00
  - 90 % Overall Simulation Completed
- Overall:
  - 180 Hours x $20.00 = $3,600.00
  - To complete the simulation plan, estimated number of hours left = 30 Hours

EVM

Earned Value Management (EVM) for SYST 490

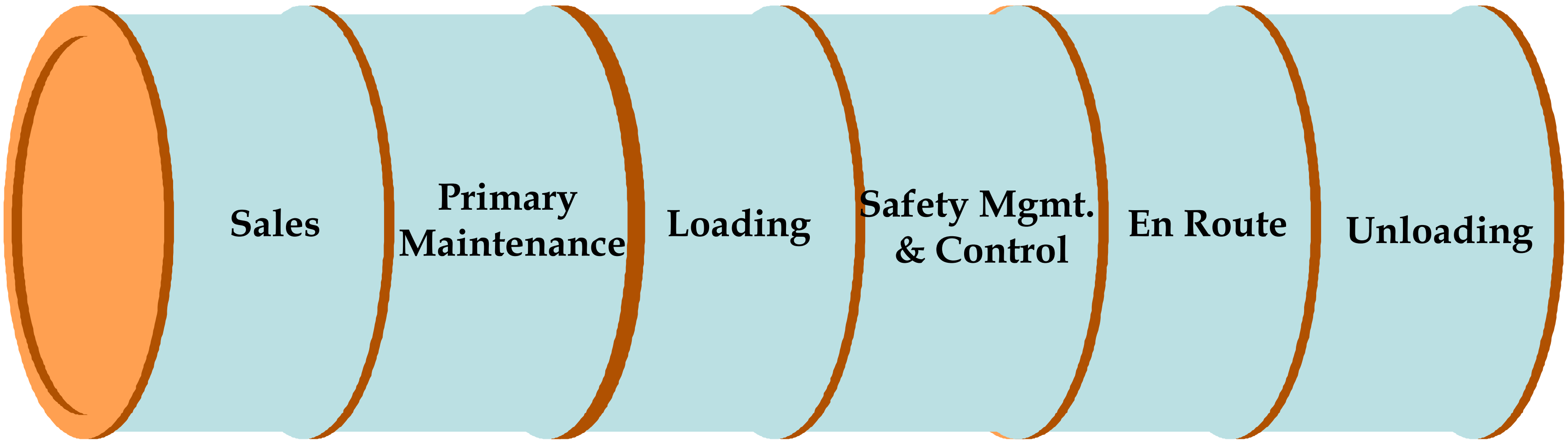


Tornado Chart

Key Cost Factors

- Start up costs including:
  - Basic operating infrastructure (OH)
  - Capital expenditures (airplanes, systems and other major equipment)
- Ongoing fixed and variable operating costs

Operational Costs of Primary Processes



Key Revenue Drivers

- Understanding our market
  - High end corporate users willing to pay a premium for a few hour's difference
    - Is the business case justifiable solely based on potential demand?
  - Government willingness to support a system that reduces congestion and increases safety
- Defining pricing policy
  - Weight vs. size

Points to Consider

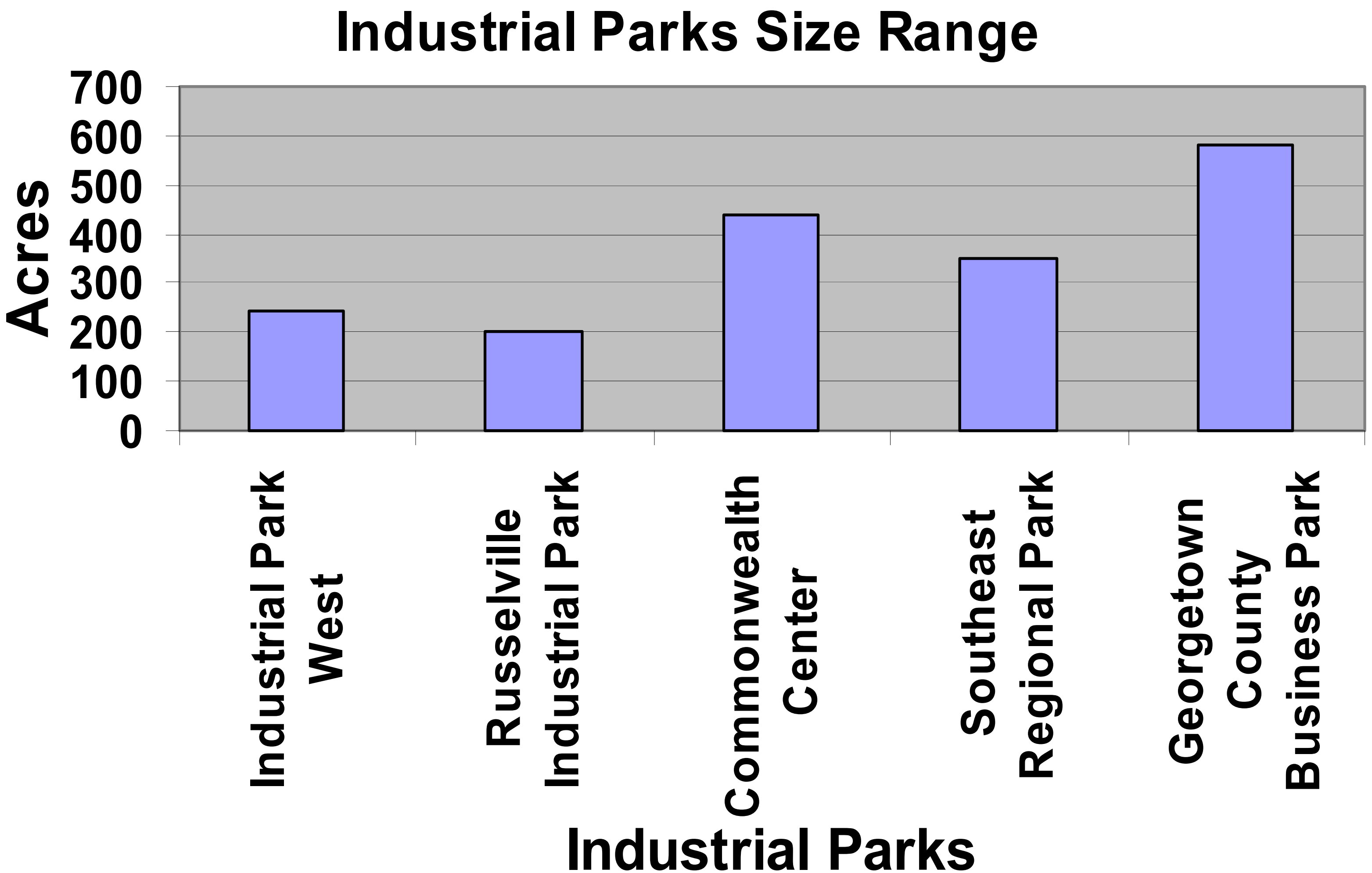
- Buy vs. lease of equipment
- Break even point considering:
  - High equipment costs as a barrier to entry
  - Economies of scale of larger operations
  - Decreasing cost of technology over time
  - Govt. subsidies made in the public interest

Cost Template

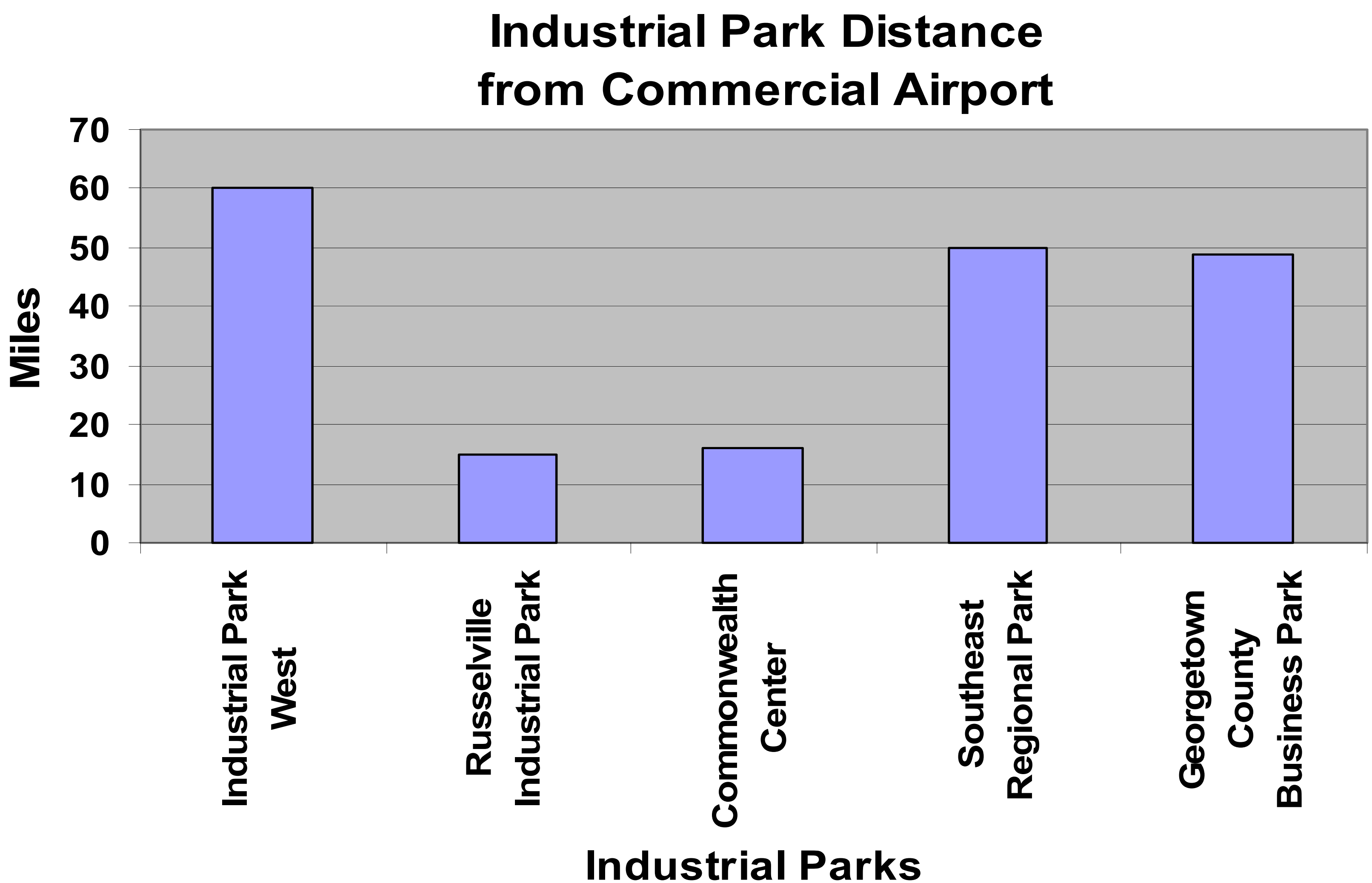
Primary Process	Associated Costs	Annual Fixed Cost	Annual Variable Cost	Annual Total Cost	Start up costs
Flight					
	ADS-B			$ -	$ 150,000
	EGPWS			$ -	$ 137,660
	Guidestar			$ -	$ 325,000
	LORAN			$ -	$ 3,945
	ModeS Transponder			$ -	$ 24,175
	Radar Altimeter			$ -	$ 31,950
	TCASII			$ -	$ 140,000
Infrastructure					
	Airplanes	$ 1,097,500		$ 1,097,500	$ -
Loading					
	Loaders			$ -	
Primary Maintenance					
	Flight mechanics	$ 898,560		$ 898,560	
	Flight system analysis			$ -	
	Refuel			$ -	
Sales					
	Advanced online order	$ -		$ -	
	Basic communications	$ 24,000		$ 24,000	
	Ground operator to determine	$ 811,637		$ 811,637	
	Ground operator to input the	$ -		$ -	
	Order entry Personnel	$ 149,760		$ 149,760	
	Order entry Personnel sends	$ -		$ -	
	Personnel to check database for	$ -		$ -	
	Plane officially scheduled	$ -		$ -	
Unloading					
	Loaders	$ 318,240		$ 318,240	$ -
Grand Total		$ 3,299,697		$ 3,299,697	$ 812,730

Cost Results

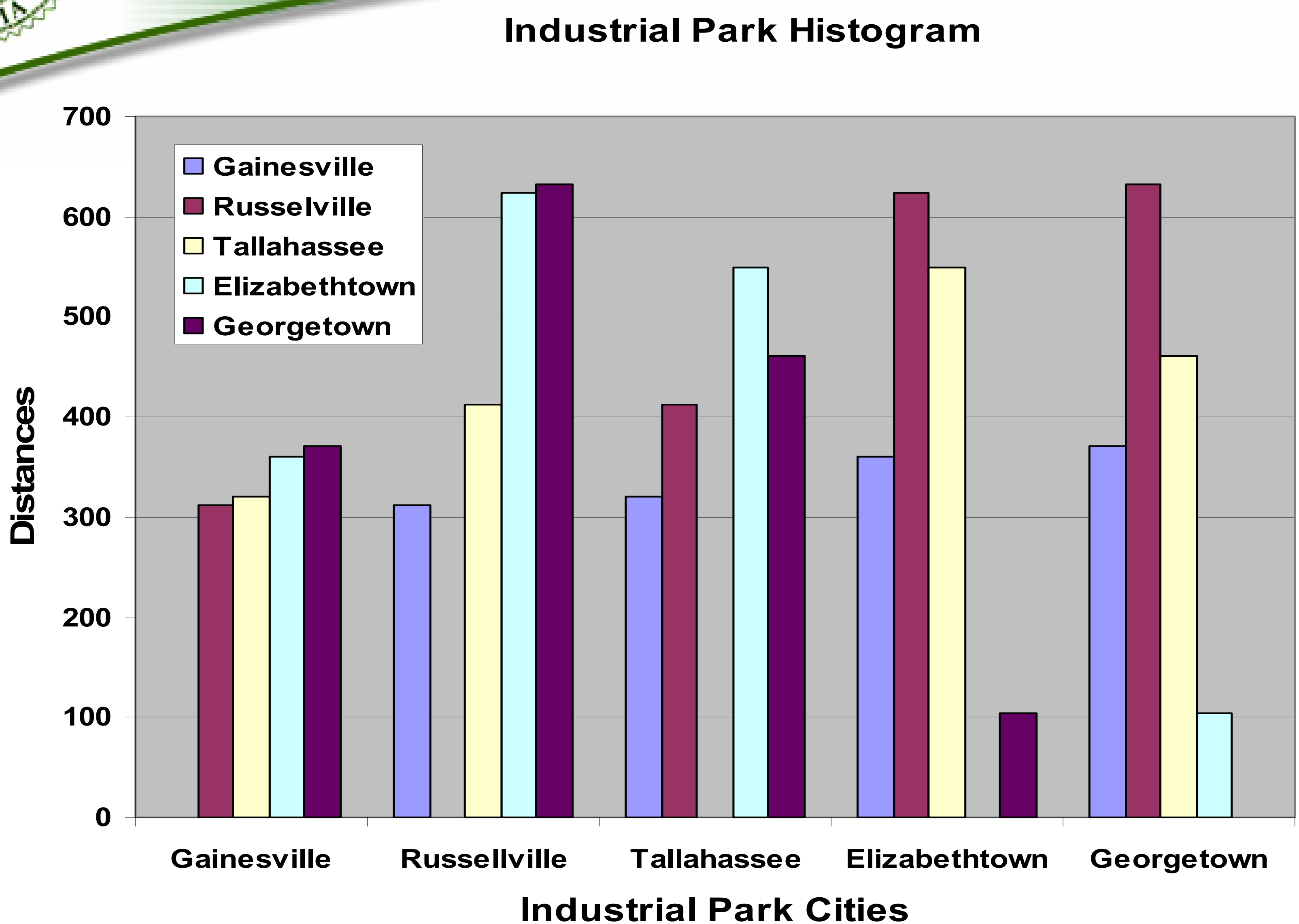
Industrial Park Size Range



Industrial Park Distance from Airport



Industrial Park Cities Distance Range



En Route Simulation Facts

- Decision Modules
  - Weather Condition
  - Maintenance
  - Flying Time
  - Delivery Time
  - Available UAV (5, 10, 15)
  - Service Requests

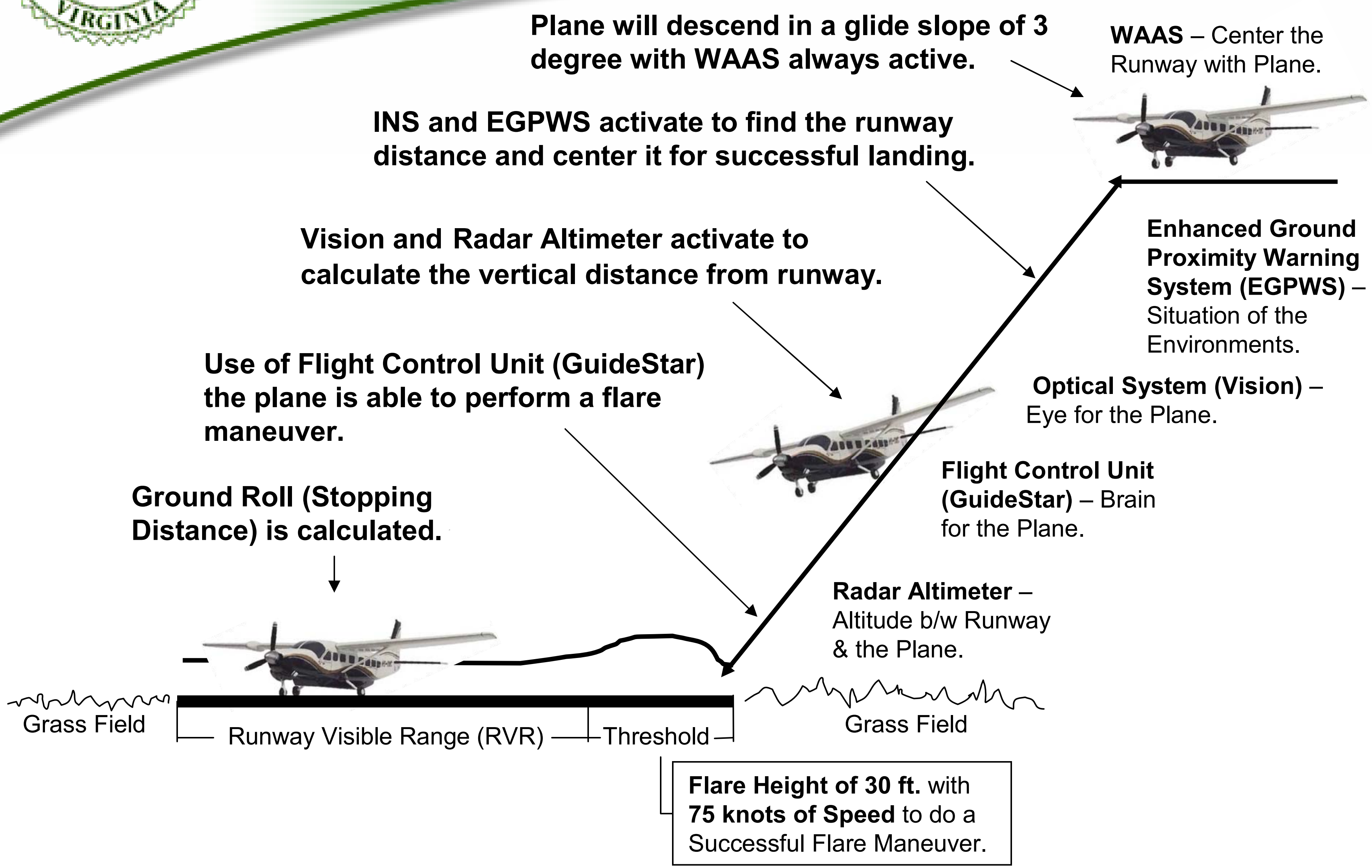
- Inputs
  - Number of Service Requests
  - Distance
    - Original city
    - Destination city

- Outputs
  - Number of success/failure
  - Number of services/day

Critical Sim. Parameters

- Weight of the Plane
- Stall Speed
- Landing Velocity
- Wing Area (S)
- Horizontal Distance (X)
- Vertical Distance Height (Y)
- Air Density (ρ)
- Lift Coefficient
- Lift
- Drag Coefficient
- Drag
- Time to Descend (Min)
- Descend Delay Time
- Height Determination
- Distance to Runway
- Distance of Flare
- Flare Descend Time
- Ground Roll
- Stopping Distance (after ground roll)

Landing Sequence



Landing Parameters

- No Taxiing & Sequencing in Simulation/Analysis Plan
- Statistical Distributions for the variables are given by the tolerance range of overall components
- Weather conditions will be simulated by having a reduced friction coefficient
- Crosswind does not exceed 20% of stall velocity
- Landing velocity cannot be less than (1.3 * stall speed)
- Hot Temperature and Humidity will affect the ground roll